

# **ZOOM LENS, CAMERA, AND MOBILE INFORMATION TERMINAL**

## **CROSS-REFERENCE TO RELATED APPLICATIONS**

The present document incorporates by reference the entire  
5 contents of Japanese priority documents, 2003-075660, 2003-076534  
and 2003-076660 filed in Japan on March 19, 2003 and 2003-126882  
filed in Japan on May 2, 2003.

## **BACKGROUND OF THE INVENTION**

### **10 1) Field of the Invention**

The present invention relates to a compact zoom lens suitable  
for a video camera and a still camera, a camera using the zoom lens as  
a shooting optical system, and a mobile information terminal using the  
zoom lens as a shooting optical system in its camera unit.

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### **2) Description of the Related Art**

Since requirements for a higher magnification, a wider angle of  
view, and a higher resolving power are increasing in the zoom lens for a  
video camera and a still camera, it is essential to reduce whole length  
20 and outer diameter of the lens, as well as the number of lenses, in  
order to realize small size, light weight, and low cost. As such a zoom  
lens, a zoom configuration has been proposed, in which a first group  
optical system having a positive refracting power, a second group  
optical system having a negative refracting power, and a third group  
25 optical system having a positive refracting power are sequentially

arranged from an object side. Zooming operation is performed by increasing the interval between the first group optical system and the second group optical system, and by decreasing the interval between the second group optical system and the third group optical system,  
5 accompanying zooming from the short focal-length side to the long focal-length side.

Such type of zoom lens having a magnification exceeding 3X is disclosed, for example, in Japanese Patent Application Laid-open No. 2000-275526, Japanese Patent Application Laid-open No. H11-242157,  
10 and Japanese Patent No. 2899019.

Another zoom lens with the magnification close to 10X is disclosed, for example, in Japanese Patent Application Laid-open No. H11-109234.

However, the configurations disclosed above cannot sufficiently  
15 satisfy the requirement for a wider angle of view, since the half angle of view at the short focal-length side is as narrow as 30 degrees.

A zoom lens with the half angle of view at the short focal-length side of about 37 degrees, which corresponds to a relatively wide angle of view, is disclosed in Japanese Patent Application Laid-open No.  
20 H11-6958. However, an F value (F number) becomes F4.1 at the short focal-length side, and F5.8 at the long focal-length side, and hence the lens becomes dark. With such a dark lens, when the size of one pixel decreases, since the image capturing device such as a charge coupled device (CCD) has a high density, the performance considerably  
25 deteriorates in a high frequency domain. Therefore, it cannot satisfy

the requirement for the high density sufficiently.

Japanese Patent Application Laid-open No. 2002-072088  
discloses a configuration corresponding to a wide angle of view, in  
which the angle of view at the short focal-length side is 45 degrees or  
5 more. However, the magnification is not larger than 2X, and hence it  
cannot sufficiently satisfy the requirement for the high magnification.

A zoom lens miniaturized for consumer products is disclosed, for  
example, in Japanese Patent No. 2920549 and Japanese Patent No.  
3091250, in which a first group optical system having a positive  
10 refracting power and not moving with zooming, a second group optical  
system having a negative refracting power and moving from an object  
side to an image surface side, from the wide-angle side toward the  
telephoto side with zooming, a third group optical system having a  
positive refracting power and moving from the image surface side to the  
15 object side, from the wide-angle side toward the telephoto side with  
zooming, and a fourth group optical system having a positive refracting  
power and not moving with zooming, are arranged in order from the  
object side to the image surface side. However, the half angle of view  
is only 25 degrees or less, and hence it is still not sufficient for  
20 obtaining a wide angle.

Furthermore, a zoom lens is disclosed, for example, in Japanese  
Patent Application Laid-open No. H6-94997, Japanese Patent  
Application Laid-open No. H10-62687, and Japanese Patent Application  
Laid-open No. H11-258507, in which the fourth group optical system in  
25 the same configuration as described above is made movable with

zooming, to perform a higher degree aberration correction, realizing small size and wide angle. The zoom lens disclosed in the Japanese Patent Application Laid-open No. H6-94997 includes the whole basic configuration in this case, but does not propose a configuration  
5 requirement sufficient for achieving small size. The zoom lens disclosed in the Japanese Patent Application Laid-open No. H10-62687 aims at miniaturization by reducing the number of pieces, but sufficient aberration correction is not performed, and does not have performance that can correspond to an image capturing device with 3,000,000 to  
10 5,000,000 pixels. The zoom lens disclosed in the Japanese Patent Application Laid-open No. H11-258507 is relatively small, and the imaging performance is better than those described above, but the half angle of view is still about 33 degrees, and hence it is still not sufficient for achieving wide angle.

15 There are many types of zoom lens for a digital camera. One of the conventional zoom lenses having a small size and a relatively high magnification is disclosed, for example, in Japanese Patent Application Laid-open No. 2002-133686, in which a first group optical system having a positive refracting power, i.e., a positive focal length, a  
20 second group optical system having a negative refracting power, i.e., a negative focal length, a third group optical system having a positive refracting power, a fourth group optical system having a positive refracting power, and a fifth group optical system having a positive refracting power are arranged in order from the object side. The  
25 respective lens groups are shifted at the time of zooming from the



wide-angle side to the telephoto side, so that the interval between the first group optical system and the second group optical system increases; the interval between the second group optical system and the third group optical system and the interval between the third group optical system and the fourth group optical system both decrease; and the interval between the fourth group optical system and the fifth group optical system increases.

However, the magnification obtained is about 3X, which is not a sufficient value for the recent requirement for high magnification. A conventional zoom lens suitable for achieving a high magnification is disclosed, for example, in Japanese Patent Application Laid-open No. 2002-156581, in which a first group optical system having a positive refracting power, a second group optical system having a negative refracting power, a third group optical system having a positive refracting power, a fourth group optical system having a positive refracting power, and a fifth group optical system having a positive refracting power are arranged in order from the object side. A diaphragm is provided on the object side of the third group optical system; and at least the second group optical system and the fourth group optical system move with zooming from the short focal-length side to the long focal-length side. However, a magnification of about 6X can be obtained, which is still not sufficient considering the recent requirement for high magnification.

## SUMMARY OF THE INVENTION

It is an object of the present invention to solve at least the problems in the conventional technology.

The zoom lens according to one aspect of the present invention includes a first group optical system having a positive refracting power, a second group optical system having a negative refracting power, a third group optical system having a positive refracting power, and a diaphragm that moves toward an object side integrally with the third group optical system. The first group optical system, the second group optical system, and the third group optical system are sequentially arranged from the object side toward an image side. At least the first group optical system and the third group optical system moves in such a manner that a distance between the first group optical system and the second group optical system becomes minimum at a short focal-length side, and a distance between the second group optical system and the third group optical system becomes minimum at a long focal-length side. The third group optical system includes a triplet lens formed by sequentially bonding a negative lens, a positive lens, and a negative lens.

The zoom lens according to another aspect of the present invention includes a first group optical system that has a positive refracting power and does not move with zooming, a second group optical system that has a negative refracting power and moves from an object side toward an image side with zooming from wide-angle side toward telephoto side, a third group optical system that has a positive refracting power and moves from the image side to the object side with

zooming from the wide-angle side toward the telephoto side, and a fourth group optical system that has a positive refracting power and does not move with zooming. The first group optical system, the second group optical system, the third group optical system, and the  
5 fourth group optical system are sequentially arranged from the object side toward an image side. The third group optical system includes a triplet lens formed by sequentially bonding a negative lens, a positive lens, and a negative lens.

The zoom lens according to still another aspect of the present  
10 invention includes a first group optical system that has a positive refracting power and does not move with zooming, a second group optical system that has a negative refracting power and moves from an object side to an image side with zooming from wide-angle side toward telephoto side, a third group optical system that has a positive  
15 refracting power and moves from the image side to the object side with zooming from the wide-angle side toward the telephoto side, and a fourth group optical system that has a positive refracting power and does not move with zooming. The first group optical system, the second group optical system, the third group optical system, and the  
20 fourth group optical system are sequentially arranged from the object side toward an image side. The third group optical system includes a triplet lens formed by sequentially bonding a negative lens, a positive lens, and a negative lens, and at least one positive lens at each of the object side and the image side of the triplet lens.

25 The zoom lens according to still another aspect of the present

invention includes a first group optical system that has a positive refracting power and does not move with zooming, a second group optical system that has a negative refracting power and moves from an object side toward an image side with zooming from wide-angle side toward telephoto side, a third group optical system that has a positive refracting power and moves from the image side to the object side with zooming from the wide-angle side toward the telephoto side, and a fourth group optical system that has a positive refracting power and moves accordingly with zooming. The first group optical system, the second group optical system, the third group optical system, and the fourth group optical system are sequentially arranged from the object side toward an image side. The third group optical system includes a triplet lens formed by sequentially bonding a negative lens, a positive lens, and a negative lens.

The zoom lens according to still another aspect of the present invention includes a first group optical system having a positive refracting power, a second group optical system having a negative refracting power, a third group optical system having a positive refracting power, a fourth group optical system having a positive refracting power, a fifth group optical system having a positive refracting power, and a diaphragm arranged at an object side of the third group optical system. The first group optical system, the second group optical system, the third group optical system, the fourth group optical system, and the fifth group optical system are sequentially arranged from the object side toward an image side. At least the

second group optical system and the fourth group optical system move with zooming from short focal-length side toward long focal-length side. The second group optical system includes a triplet lens formed by sequentially bonding a negative lens, a positive lens, and a negative  
5 lens from the object side.

The camera according to still another aspect of the present invention uses the zoom lens according to the above aspects as a shooting optical system.

The mobile information terminal according to still another aspect  
10 of the present invention uses the zoom lens according to the above aspects as a shooting optical system for its camera unit.

The other objects, features, and advantages of the present invention are specifically set forth in or will become apparent from the following detailed descriptions of the invention when read in conjunction  
15 with the accompanying drawings.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

Fig. 1 is a schematic diagram of an optical system of example 1-1 of a zoom lens according to a first embodiment of the present  
20 invention;

Fig. 2 is a schematic diagram of an optical system of example 1-2 of the zoom lens according to the first embodiment;

Fig. 3 is a schematic diagram of an optical system of example 1-3 of the zoom lens according to the first embodiment;

25 Fig. 4 is a schematic diagram of an optical system of example

1-4 of the zoom lens according to the first embodiment;

Fig. 5 is a schematic diagram of an optical system of example

1-5 of the zoom lens according to the first embodiment;

Fig. 6 is a schematic diagram of an optical system of example

5 1-6 of the zoom lens according to the first embodiment;

Fig. 7 is a schematic diagram of an optical system of example

1-7 of the zoom lens according to the first embodiment;

Fig. 8 is a set of graphs for illustrating aberration characteristics  
of the zoom lens shown in Fig. 1;

10 Fig. 9 is a set of graphs for illustrating aberration characteristics  
of the zoom lens shown in Fig. 2;

Fig. 10 is a set of graphs for illustrating aberration  
characteristics of the zoom lens shown in Fig. 3;

15 Fig. 11 is a set of graphs for illustrating aberration  
characteristics of the zoom lens shown in Fig. 4;

Fig. 12 is a set of graphs for illustrating aberration  
characteristics of the zoom lens shown in Fig. 5;

Fig. 13 is a set of graphs for illustrating aberration  
characteristics of the zoom lens shown in Fig. 6;

20 Fig. 14 is a set of graphs for illustrating aberration  
characteristics of the zoom lens shown in Fig. 7;

Fig. 15 is a set of graphs for illustrating aberration  
characteristics of the zoom lens shown in Fig. 6 when a beam flux of a  
mean image height at the short focal-length side and a mean focal  
25 length is shielded by a diaphragm;

Fig. 16 is a schematic diagram of a digital camera according to a second embodiment of the present invention, which has a range-finder-type optical finder;

Fig. 17 is a block diagram of a digital camera or a mobile  
5 information terminal according to the second embodiment;

Fig. 18 is a schematic diagram of a digital camera according to a third embodiment of the present invention, which has a single-lens reflex-type optical finder;

Fig. 19 is a schematic diagram of an optical system of example  
10 2-1 of a zoom lens according to a fourth embodiment of the present invention;

Fig. 20 is a schematic diagram of an optical system of example 2-2 of the zoom lens according to the fourth embodiment;

Fig. 21 is a schematic diagram of an optical system of example  
15 2-3 of the zoom lens according to the fourth embodiment;

Fig. 22 is a schematic diagram of an optical system of example 2-4 of the zoom lens according to the fourth embodiment;

Fig. 23 is a schematic diagram of an optical system of example 2-5 of the zoom lens according to the fourth embodiment;

Fig. 24 is a schematic diagram of an optical system of example  
20 2-6 of the zoom lens according to the fourth embodiment;

Fig. 25 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 37 at the short focal-length side;

Fig. 26 is a set of graphs for illustrating aberration  
25

characteristics of the zoom lens shown in Fig. 19 at the mean focal length;

Fig. 27 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 19 at the long focal  
5 length;

Fig. 28 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 20 at the short focal length;

Fig. 29 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 20 at the mean focal  
10 length;

Fig. 30 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 20 at the long focal length;

Fig. 31 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 21 at the short focal  
15 length;

Fig. 32 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 21 at the mean focal  
20 length;

Fig. 33 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 21 at the long focal length;

Fig. 34 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 22 at the short focal  
25



length;

Fig. 35 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 22 at the mean focal length;

5            Fig. 36 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 22 at the long focal length;

Fig. 37 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 23 at the short focal  
10   length;

Fig. 38 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 23 at the mean focal length;

Fig. 39 is a set of graphs for illustrating aberration  
15   characteristics of the zoom lens shown in Fig. 23 at the long focal length;

Fig. 40 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 24 at the short focal length;

20            Fig. 41 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 24 at the mean focal length;

Fig. 42 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 24 at the long focal  
25   length;

Fig. 43 is a schematic diagram of an optical system of example 3-1 of a zoom lens according to a fifth embodiment of the present invention;

Fig. 44 is a schematic diagram of an optical system of example 3-2 of the zoom lens according to the fifth embodiment;

Fig. 45 is a schematic diagram of an optical system of example 3-3 of the zoom lens according to the fifth embodiment;

Fig. 46 is a schematic diagram of an optical system of example 3-4 of the zoom lens according to the fifth embodiment;

Fig. 47 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 43 at the short focal-length side;

Fig. 48 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 43 at the mean focal-length side;

Fig. 49 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 43 at the long focal-length side;

Fig. 50 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 44 at the short focal-length side;

Fig. 51 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 44 at the mean focal-length side;

Fig. 52 is a set of graphs for illustrating aberration

characteristics of the zoom lens shown in Fig. 44 at the long focal-length side;

Fig. 53 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 45 at the short focal-length side;

Fig. 54 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 45 at the mean focal-length side;

Fig. 55 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 45 at the long focal-length side;

Fig. 56 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 46 at the short focal-length side;

Fig. 57 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 46 at the mean focal-length side;

Fig. 58 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 46 at the long focal-length side;

Fig. 59 is a schematic diagram of an optical system of example 4-1 of a zoom lens according to a sixth embodiment of the present invention;

Fig. 60 is a schematic diagram of an optical system of example 4-2 of the zoom lens according to the sixth embodiment;

Fig. 61 is a schematic diagram of an optical system of example 4-3 of the zoom lens according to the sixth embodiment;

Fig. 62 is a schematic diagram of an optical system of example 4-4 of the zoom lens according to the sixth embodiment;

5        Fig. 63 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 59 at the short focal-length side;

      Fig. 64 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 59 at the mean  
10    focal-length side;

      Fig. 65 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 59 at the long focal-length side;

      Fig. 66 is a set of graphs for illustrating aberration  
15    characteristics of the zoom lens shown in Fig. 60 at the short focal-length side;

      Fig. 67 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 60 at the mean focal-length side;

20        Fig. 68 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 60 at the long focal-length side;

      Fig. 69 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 61 at the short  
25    focal-length side;

Fig. 70 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 61 at the mean focal-length side;

Fig. 71 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 61 at the long focal-length side;

Fig. 72 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 62 at the short focal-length side;

Fig. 73 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 62 at the mean focal-length side;

Fig. 74 is a set of graphs for illustrating aberration characteristics of the zoom lens shown in Fig. 62 at the long focal-length side;

Fig. 75 is a perspective view of a camera according to a first mode of a seventh embodiment of the present invention, with a shooting lens retracted in the camera body seen from an object side;

Fig. 76 is a perspective view of the camera according to the first mode of the seventh embodiment, with the shooting lens extended from the camera body seen from the object side;

Fig. 77 is a perspective view of the camera shown in Fig. 75, seen from a photographer side;

Fig. 78 is a perspective view of a camera according to a second mode of the seventh embodiment, with a shooting lens retracted in the

camera body seen from an object side;

Fig. 79 is a perspective view of the camera according to the second mode of the seventh embodiment, with the shooting lens extended from the camera body seen from the object side;

5 Fig. 80 is a perspective view of the camera shown in Fig. 78, seen from a photographer side; and

Fig. 81 is a block diagram of the camera according to the seventh embodiment.

## 10 DETAILED DESCRIPTION

Exemplary embodiments of a zoom lens, a camera, and a mobile information terminal according to the present invention will be explained in detail with reference to the accompanying drawings.

A first embodiment of the present invention explains the zoom  
15 lens according to the present invention. At first, a fundamental configuration of the zoom lens according to the first embodiment is explained, followed by a specific configuration of the zoom lens according to the first embodiment, by enumerating specific numerical examples as example 1-1 to example 1-7, and with reference to Fig. 1  
20 to Fig. 15.

The zoom lens according to the first embodiment includes a first group optical system having a positive refracting power, a second group optical system having a negative refracting power, a third group optical system having a positive refracting power, and a diaphragm that moves  
25 toward an object side integrally with the third group optical system.

The first group optical system, the second group optical system, and the third group optical system are sequentially arranged from the object side toward an image side. At least the first group optical system and the third group optical system moves in such a manner that a distance  
5 between the first group optical system and the second group optical system becomes minimum at a short focal-length side, and a distance between the second group optical system and the third group optical system becomes minimum at a long focal-length side. The third group optical system includes a triplet lens formed by sequentially bonding a  
10 negative lens, a positive lens, and a negative lens.

The configuration of the third group optical system in the conventional zoom lens of this type is obtained by using three lenses having positive, negative, and positive refracting powers, or four lenses having positive, positive, negative, and positive refracting powers,  
15 wherein two lenses thereof are cemented together according to need.

In the present invention, by having a configuration including a triplet having negative, positive, and negative lenses in the third group optical system, two cementing surfaces at different positions from the diaphragm are arranged, and by using the fact that the beams pass  
20 through in different ways on the axis and off the axis on the two cementing surfaces, axial and off-axis chromatic aberrations can be corrected individually to some extent. This has a large effect particularly on the correction of chromatic aberration of magnification resulting from achieving a wide angle of view. As a method for  
25 obtaining two cementing surfaces, two sets of doublets can be arranged.

However, when a deviation from the optical axis occurs in the two sets of doublets due to an assembly deviation, chromatic aberration of magnification occurs asymmetrically, to cause unnatural color blur. In the case of a triplet, since the deviation from the optical axis on the two cementing surfaces can be suppressed, chromatic aberration of magnification can be corrected more favorably, as compared with the two sets of doublets.

The specific shift of each group is, for example, as in example 1-1 illustrated in Fig. 1, such that the second group optical system G2 is fixed with respect to the image surface, the first group optical system G1 moves toward the object side, from the short focal-length side (Wide) to the long focal-length side (Tele), and the third group optical system G3 moves toward the object side from the short focal-length side to the long focal-length side.

As another example, as illustrated in example 1-2 to example 1-4 illustrated in Fig. 2 to Fig. 4, the first group optical system G1 moves toward the image surface side from the short focal-length side to the mean focal length (Mean), and then toward the object side from the mean focal length to the long focal-length side. The second group optical system G2 moves toward the object side from the short focal-length side to the long focal-length side; and the third group optical system G3 moves toward the object side from the short focal-length side to the long focal-length side.

In example 1-5 illustrated in Fig. 5, the shifts of the first group optical system G1 and the second group optical system G2 are similar



to those in Fig. 2 to Fig. 4, but the third group optical system G3 moves toward the object side from the short focal-length side to the mean focal length, and moves toward the image surface side from the mean focal length to the long focal-length side.

5           As an another example, as in example 1-6 and example 1-7 illustrated in Fig. 6 and Fig. 7, the first group optical system G1 moves toward the object side from the short focal-length side to the long focal-length side, the second group optical system G2 moves toward the image surface side from the short focal-length side to the long  
10 focal-length side, and the third group optical system G3 moves toward the object side from the short focal-length side to the long focal-length side.

          In such a zoom lens, in any case of example 1-1 to example 1-7 illustrated in Fig. 1 to Fig. 7, the first group optical system G1 moves in  
15 a trajectory forming a convex shape toward the image surface side. The second group optical system G2 moves monotonously or in a trajectory slightly forming a convex shape toward the image surface side, and the third group optical system G3 moves monotonously or in a trajectory forming a convex shape toward the object side. By moving  
20 the respective groups in this manner, zooming is performed mainly by the shift of the second group optical system G2, and zooming and a variation in the image surface position accompanying zooming are corrected by the way of movement of other groups.

          As in example 1-2 to example 1-4 illustrated in Fig. 2 to Fig. 4,  
25 the first group optical system G1 may be shifted to a position closest to

the image surface at a focal length other than at the short focal-length side and the long focal-length side, so that the first group optical system G1 performs correction of a variation in the image surface position accompanying zooming.

5           The negative lens closest to the object side of the triplet including negative, positive, and negative lenses arranged in the third group optical system G3 may be arranged with a strong concave face facing the image surface side. The surface on the object side of the negative lens closest to the object side is made to have a refracting  
10 power as weak as possible, to suppress the occurrence of unnecessary aberrations, and spherical aberration and comatic aberration are corrected mainly by the surfaces on the image surface side. Preferably, the zoom satisfies a relation

$$0.6 < K12 / (f_w + f_t) < 1.2 \quad (1)$$

15 where K12 is changing amount of a distance between the first group optical system and the second group optical system,  $f_w$  is a combined focal length of whole system at the short focal-length side, and  $f_t$  is a combined focal length of the whole system at the long focal-length side.

This conditional expression (1) is for regulating a variation in the  
20 interval between the first group optical system G1 and the second group optical system G2 mainly due to zooming, and when  $\{K12 / (f_w + f_t)\}$  exceeds the upper limit, the fluctuations of the first group optical system G1 and the second group optical system G2 increase. Accordingly, the zoom lens itself becomes large, and the front-cell diameter increases,  
25 and hence miniaturization cannot be achieved. On the other hand, if

{ $K_{12}/(f_w+f_t)$ } is smaller than the lower limit, the power of the first group optical system G1 and the second group optical system G2 becomes too strong, thereby increasing the occurrence of aberrations in the respective groups, and performance degradation due to a

5 manufacturing error such as a deviation from the center increases. As a result, excellent imaging performance cannot be obtained.

Furthermore, the zoom lens satisfies relations

$$-0.22 < N_p - N_n < 0 \text{ and} \quad (2)$$

$$3 < v_p - v_n < 36 \quad (3)$$

10 where  $N_p$  and  $v_p$  are a refractive index and an Abbe constant of the positive lens of the triplet lens, respectively, and  $N_n$  and  $v_n$  are an average of refractive indexes and an average of Abbe constants of the two negative lenses of the triplet lens .

These conditional expressions (2) and (3) are for giving a  
15 condition for performing excellent correction of chromatic aberration, and when { $N_p - N_n$ } is smaller than the lower limit of the conditional expression (2), or { $v_p - v_n$ } exceeds the upper limit of the conditional expression (3), excellent ability for correcting chromatic aberration can be obtained, but the glass material of the positive lens becomes very  
20 expensive. On the contrary, when { $N_p - N_n$ } exceeds the upper limit of the conditional expression (2), or { $v_p - v_n$ } is smaller than the lower limit of the conditional expression (3), it becomes difficult to maintain the balance between on-axis chromatic aberration and other aberrations favorably, and particularly, on-axis chromatic aberration at the long  
25 focal-length side increases, and the ability for correcting chromatic

aberration on the cementing surface on the object side considerably deteriorates.

The third group optical system further includes at least one positive lens at each of the object side and the image side of the triplet lens. Since the triplet has two strong concave surfaces, it is necessary to arrange a positive refracting power opposing the negative refracting power thereof. By arranging a positive lens both on the object side and the image surface side of the triplet, the third group optical system G3 has a configuration of positive, negative, positive, negative, and positive, and the well-balanced refracting power can be arranged. As a result, the occurrence of aberrations on one lens surface can be effectively suppressed, and performance degradation due to a manufacturing error, such as a deviation from the center, can be also suppressed.

At least one positive lens from among the positive lenses arranged at the object side and the image side of the triplet lens is an aspheric lens. By forming an aspheric surface on at least one of the positive lenses arranged on the object side and the image surface side of the triplet in the third group optical system G3, the whole length of the third group optical system G3 can be reduced. When the aspheric surface is formed on the lens on the object side, since the aspheric surface is arranged at a position close to the diaphragm, it is effective mainly for correction of spherical aberration and comatic aberration. When the aspheric surface is formed on the lens on the image surface side, since the aspheric surface is arranged at a position away from the

diaphragm, it can be arranged at a position where the beams on the axis and off the axis are separated, and hence it is effective mainly for correction of astigmatism.

Furthermore, each of the first group optical system and the  
5 second group optical system includes at least one positive lens and one negative lens. In order to obtain high-performance lens, it is necessary to suppress the respective aberrations. In order to favorably correct the respective aberrations, it is necessary to increase the number of lenses to some extent, to suppress the occurrence of  
10 aberrations in each lens. However, when the number of lenses increases, each group becomes thick, and hence miniaturization of the whole zoom lens cannot be achieved, and the mechanism becomes complicated, thereby causing a cost increase in production and the like. Therefore, the zoom lens according to the present invention has a  
15 configuration such that the first group optical system G1 and the second group optical system G2 include at least one positive lens and negative lens, which is a minimum requirement for correcting aberrations. Specifically, the first group optical system G1 has a triple configuration of negative, positive, and positive lenses, or a double configuration of  
20 negative and positive lenses, and the second group optical system G2 has a triple configuration of negative, negative, and positive lenses. In order to favorably maintain the imaging performance with such a configuration of a fewer lenses, it is further desired to provide at least one aspheric surface in the first group optical system G1 or the second  
25 group optical system G2.

A camera according to a second embodiment of the present invention uses the zoom lens according to the first embodiment as the shooting optical system.

The camera according to the second embodiment is for  
5 recording an image of a subject via the zoom lens according to the present invention. By employing the zoom lens in a film camera, a digital still camera, or a digital video camera, a compact camera of an electric power saving type, which can obtain a high variable power and high image quality, can be obtained. Further, it is desired that the  
10 light-receiving image capturing device that receives light of the subject image by the zoom lens have 3,000,000 pixels or more. As the number of pixels increases, the light-receiving image capturing device can improve the recording density of the subject image. Therefore, by having 3,000,000 pixels or more, even when the subject image  
15 recorded by the camera of the present invention is printed out, an output image having the quality the same as that of the conventional film camera or higher can be obtained.

Fig. 16 is a schematic diagram of a digital camera according to a second embodiment of the present invention, which has a  
20 range-finder-type optical finder. An image capturing device 51 includes a shooting zoom optical system 52 that captures a subject optically to image the subject image, and a solid image capturing device 53, such as a CCD image capturing device that photoelectrically exchanges the subject image imaged by the shooting zoom optical  
25 system 52. Further, according to need, a finder optical system 71 of a

range finder type for visually checking the shooting range of the subject.

Fig. 18 is a schematic diagram of a digital camera having a single-lens reflex-type optical finder. The image capturing device 51 includes a shooting zoom optical system 52 that captures a subject optically to image the subject image, and a solid image capturing device 53, such as a CCD image capturing device that photoelectrically exchanges the subject image imaged by the shooting zoom optical system 52, as in the example illustrated in Fig. 16. In this case, a finder optical system 81 of a single-lens reflex type is used for visually checking the shooting range of the subject. In other words, the finder optical system 81 includes a movable reflex mirror 82, which is inserted in a subject image imaging optical path in the shooting zoom optical system 52, at the time of visually checking the shooting range, to deflection-reflect the optical path to guide it to a finder optical path, and at the time of shooting, is evacuated (82A) from the subject image imaging optical path in the shooting zoom optical system 52, a focusing screen 83 for imaging the subject image at the time of visually checking the shooting range, a pentaprism 84 for forming a bent finder optical path for observing the imaging state of the focusing screen 83, and an eyepiece 85 for observing the image on the focusing screen 83 guided by the pentaprism 84 as an actual image.

The shooting zoom optical system 52 is formed by using a zoom lens corresponding to any of the examples according to the first embodiment, and a solid image capturing device 53 is arranged at a

predetermined position at the back thereof, via a shutter of a focal plane type or the like (not shown).

The configuration of one example of the control system in the image capturing device 51 in the camera according to the second and the third embodiments is illustrated in Fig. 17. The shooting zoom  
5 optical system 52 includes a shooting zoom lens 52a corresponding to any of the examples according to the first embodiment, and a mechanical drive mechanism 52b that mechanically drives the shooting zoom lens 52a. The mechanical drive mechanism 52b includes, for  
10 example, an auto focus mechanism, a mechanical shutter mechanism, and a zoom mechanism that changes the intervals between the zoom lens groups.

The subject image guided by the optical system is imaged on the solid image capturing device 53, and photoelectrically exchanged  
15 after the colors are separated by a filter (not shown) arranged on the solid image capturing device 53, and output as an analog image signal of R (red), G (green), and B (blue). The output analog signal is subjected to noise reduction in the image signal by a correlated double sampling (CDS) circuit, and adjustment of the image signal level by an  
20 auto gain control (AGC) circuit, in a signal processor 54. The signal having passed through the signal processor 54 enters into an analog-to-digital (A/D) converter 55, where the analog image data is converted to digital image data having an optimum sampling frequency. The digital image data is subjected to digital signal processing including  
25 white balance adjustment for adjusting the gain of the respective R and



G signals, and image processing such as processing for separating the digital image data to color difference and luminance in a digital signal processor 56. The image data digitalized by the digital signal processor 56 is temporarily stored in an image memory 57.

5           A controller 58 has a central processing unit (CPU), a read only memory (ROM), a random access memory (RAM), and the like.

According to a program stored in the ROM, the CPU operates, using the RAM as a work area, to perform control of the whole system. For example, a motor driver 59 for driving and operating the mechanical  
10   drive mechanism 52b operates based on a control signal from the controller 58, to drive the mechanical drive mechanism 52b in the zoom optical system 52. A timing control circuit 60 controls generation of a drive control signal with respect to the solid image capturing device 53, signal processing, and the timing of the A/D conversion in the A/D  
15   converter 55.

When a camera is constructed by using the above configuration, for example as illustrated in Fig. 17, a data recorder 61 for recording the shot image, for example by using media such as a flash memory card is provided in addition to the image capturing device 51, and  
20   further according to need, a display 62 that displays the shooting range by a liquid crystal display (LCD) or the like is provided.

Further, in order to shoot a dark subject, a strobe unit 63 may be equipped, and when a dark subject is shot under an insufficient quantity of light, an adequate shooting becomes possible by illuminating the  
25   subject by the strobe unit 63.

A mobile information terminal according to a third embodiment of the present invention uses the zoom lens according to the first embodiment as a shooting optical system in its camera unit. In the third embodiment, the mobile information terminal is formed, in which  
5 the functional configuration similar to that of the camera in the second embodiment is incorporated as the camera unit. In other words, the zoom lens according to the first embodiment is used in the camera unit included in the mobile information terminal, as the shooting zoom optical system. The configuration similar to that of the camera  
10 described with reference to Fig. 16 and Fig. 17 is incorporated to constitute the mobile information terminal.

Fig. 18 is a schematic diagram of a digital camera according to a third embodiment of the present invention, which has a single-lens reflex-type optical finder

15 The mobile information terminal further includes a communication interface (I/F) 64 for transmitting image data shot and recorded by the camera to a personal computer PC or the like via a communication system, in addition to the configuration of the camera as illustrated in Fig. 18, to constitute the camera unit.

20 In such a mobile information terminal, the mobile information terminal can be made considerably small, by using the camera as a built-in camera unit, thereby obtaining high quality recorded data.

A fourth embodiment of the present invention explains the zoom lens according to the present invention. At first, a fundamental  
25 configuration of the zoom lens according to the fourth embodiment is

explained, followed by a specific configuration of the zoom lens according to the fourth embodiment, by enumerating specific numerical examples as example 2-1 to example 2-6, and with reference to Fig. 1 to Fig. 42.

5           In the zoom lens according to the fourth embodiment, a first group optical system having a positive refracting power, a second group optical system having a negative refracting power, a third group optical system having a positive refracting power, and a fourth group optical system having a positive refracting power are sequentially arranged  
10 from the object side toward the image surface, that is, four group optical systems of positive-negative-positive-positive are arranged. In the configuration of a certain zoom lens, the second group optical system moves from the object side to the image surface side, and the third group optical system moves from the image surface side to the object  
15 side, accompanying zooming from the wide-angle side toward the telephoto side.

          In the configuration of another zoom lens according to the fourth embodiment, the second group optical system moves from the object side to the image surface side, and the third group optical system  
20 moves from the image surface side to the object side, accompanying zooming from the wide-angle side toward the telephoto side, and the fourth group optical system also moves. This fourth group optical system is a group optical system that mainly performs a role of correcting the shift of the image surface, with the shifts of the second  
25 and the third group optical systems. In order to realize a zoom lens

having less various aberrations and having a high resolving power, aberration fluctuation due to zooming should be suppressed, and particularly, it is necessary that aberration correction of the third group optical system, which takes responsibility of zooming action, or two  
5 actions, that is, zooming and image surface correction, is performed favorably over the whole area of the zooming range. Further, in order to achieve a wide angle of view at the wide-angle side, it is necessary to reduce the chromatic aberration of magnification, which increases with achievement of the wide angle of view. In order to correct this  
10 favorably in the whole area of the zooming range, the configuration of the third group optical system is important.

Conventionally, as the configuration of the third group optical system, one having a two-piece configuration in which a positive lens and a negative lens are sequentially arranged from the object side to  
15 the image surface side, one having a three-piece configuration in which a positive lens, a negative lens, and a positive lens are sequentially arranged, and one having a three-piece configuration in which a positive lens, a positive lens, and a negative lens are sequentially arranged are known. However, the present invention is for realizing  
20 the third group optical system having an aberration correction ability exceeding these. Namely, in the zoom lens according to the fourth embodiment, the third group optical system has a configuration including a triplet obtained by cementing a negative lens, a positive lens, and a negative lens. The two cementing surfaces have different  
25 distances from the diaphragm, and the way of passage of the beams on

the axis and off the axis is also different. The on-axis chromatic aberration and the chromatic aberration of magnification can be corrected independently to some extent, by such two cementing surfaces, and as a result, it is effective for correction of chromatic  
5 aberration of magnification, which increases with achievement of a wide angle of view. In order to provide two cementing surfaces, it can be considered to use two sets of cemented lenses, but when the optical axes of the two cemented lenses are deviated from each other, due to a deviation at the time of assembly, chromatic aberration of magnification  
10 occurs asymmetrically off the axis, and as a result, unnatural color blur is likely to occur.

On the other hand, when the triplet is used as described above, a deviation at the time of assembly does not occur on the two cementing surfaces, and chromatic aberration of magnification can be  
15 reduced sufficiently in the actual configuration.

In order to perform more sufficient correction of aberrations, the negative lens of the triplet arranged closest to the object side in the third group optical system is desirably in a meniscus shape with the concave facing the image side. The surface on the object side of the  
20 negative lens is a convex surface so as to prevent occurrence of unnecessary aberrations, without largely refracting the incident beams, and the image surface side of the negative lens is a strong concave, so as to mainly perform correction of spherical aberration and comatic aberration. Further, in order to perform sufficient correction of  
25 aberrations, it is desired that the negative lens of the triplet arranged

closest to the image side in the third group optical system have a strong concave facing the image side. The surface on the image side of the negative lens is a strong concave, so as to perform secondary correction of spherical aberration and comatic aberration, and also  
5 contribute to the correction of astigmatism.

Further, it is desired to satisfy the following conditional expressions in order to perform favorable correction of chromatic aberration.

$$1.45 < N_{c2} < 1.52 \quad (4)$$

10  $68 < v_{c2} < 85 \quad (5)$

where  $N_{c2}$  and  $v_{c2}$  respectively denote a refractive index and an Abbe constant of the positive lens arranged in the middle of the triplet in the third group optical system. If  $N_{c2}$  is not smaller than 1.52, and  $v_{c2}$  is not larger than 68, it becomes difficult to balance the on-axis chromatic  
15 aberration against other aberrations, and particularly, the on-axis chromatic aberration at the long focal-length side is likely to occur. In this case, the correction effect of monochromatic aberration on the cementing surface on the object side cannot be obtained sufficiently. On the other hand, if  $N_{c2}$  is not larger than 1.45, and  $v_{c2}$  is not smaller  
20 than 85, it is advantageous in view of the correction of aberrations, but such a glass material is expensive, thereby causing an unnecessary cost increase.

In order to correct the chromatic aberration of magnification more favorably, it is desired to satisfy the following conditional  
25 expressions.

$$1.60 < N_{c1} < 1.95 \quad (6)$$

$$20 < v_{c1} < 40 \quad (7)$$

$$1.60 < N_{c3} < 1.95 \quad (8)$$

$$20 < v_{c3} < 40 \quad (9)$$

5 where  $N_{c1}$  and  $v_{c1}$  respectively denote a refractive index and an Abbe constant of the negative lens of the triplet arranged closest to the object side in the third group optical system, and  $N_{c3}$  and  $v_{c3}$  respectively denote a refractive index and an Abbe constant of the negative lens of the triplet arranged closest to the image side in the third group optical system. By satisfying these conditional expressions, together with the conditional expressions relating to  $N_{c2}$  and  $v_{c2}$ , the on-axis chromatic aberration can be balanced against the chromatic aberration of magnification, and particularly, the chromatic aberration of magnification at the short focal-length side can be reduced. At this time, the corrected state of monochromatic aberration can be also maintained favorably.

In order to further improve the monochromatic aberration, it is desired to satisfy the following conditional expression.

$$0.25 < (R_{c2}/R_{c4}) < 1.25 \quad (10)$$

20 where  $R_{c2}$  denotes a radius of curvature of the cementing surface on the object side of the triplet in the third group optical system, and  $R_{c4}$  denotes a radius of curvature of the surface closest to the image side of the triplet in the third group optical system. If  $(R_{c2}/R_{c4})$  is not smaller than 1.25, the spherical aberration at the long focal-length side is likely to occur largely in the positive direction, thereby causing deterioration

in the image contrast. On the other hand, if ( $R_{c2}/R_{c4}$ ) is not larger than 0.25, the correction ability of astigmatism and curvature of field becomes insufficient, thereby causing deterioration in flatness of the image surface, over the whole area of the zooming range.

5           In the zoom lens according to the fourth embodiment, it is further desired that the third group optical system have a triplet including a negative lens, a positive lens, and a negative lens, and positive lenses provided at least one each respectively on the object side and the image side of the triplet. The triplet has two concaves  
10   having a strong negative refracting power, and in order to pull out the aberration correction ability thereof sufficiently, it is necessary to arrange a positive refracting power against it. If a positive lens is respectively arranged on the object side and the image side of the triplet, the third group optical system has a configuration of  
15   positive-negative-positive-negative-positive, thereby having a good balance as the arrangement of the refracting power. By having such an arrangement, occurrence of excessive aberrations can be prevented on one lens surface, and deterioration in development due to a manufacturing error such as a deviation can be suppressed.

20           Further, in order to make the third group optical system small, and particularly, to reduce the whole length thereof, it is effective to use an aspheric surface in the third group optical system. At this time, the aspheric surface is preferably provided either one or both of the positive lenses arranged on the object side and the image side of the triplet.

25   The positive lens on the object side is close to the diaphragm, and is



effective mainly for the correction of spherical aberration and comatic aberration. The positive lens on the image side is away from the diaphragm, and off-axis beams pass through, being separated from each other to some extent. Therefore, it is effective for the correction  
5 of astigmatism, as well as correction of spherical aberration and comatic aberration.

In the zoom lens according to the fourth embodiment, a configuration in which the fourth group optical system is shifted can be considered. By adopting such a configuration, and considering various  
10 movements associated with the third group optical system, a higher magnification, a wider angle of view, and miniaturization can be achieved.

A fifth embodiment of the present invention explains the zoom lens according to the present invention. At first, a fundamental  
15 configuration of the zoom lens according to the fifth embodiment is explained, followed by a specific configuration of the zoom lens according to the fifth embodiment, by enumerating specific numerical examples as example 3-1 to example 3-4, and with reference to Fig. 43 to Fig. 58.

20 The zoom lens according to the fifth embodiment includes a first group optical system G1 having a positive focal length, a second group optical system G2 having a negative focal length, a third group optical system G3 having a positive focal length, a fourth group optical system G4 having a positive focal length, and a fifth group optical system G5  
25 having a positive focal length, arranged in order from the object side to

the image surface side. A diaphragm FA is provided on the object side of the third group optical system, and at least the second group optical system and the fourth group optical system move, accompanying zooming from the short focal-length side toward the long focal-length side. Further, the zoom lens is formed in various modes having features described below.

The zoom lens according to a first mode is such that the second group optical system G2 includes a triplet including a negative lens, a positive lens, and a negative lens in order from the object side toward the image surface side. The zoom lens according to a second mode is such that the negative lens arranged closest to the object side of the triplet in the second group optical system G2 is a double-concave lens.

The zoom lens according to the third mode is such that, in the zoom lens in the first mode, the negative lens arranged closest to the object side of the triplet in the second group optical system G2 is a double-concave lens.

The zoom lens according to the fourth mode is such that, in the zoom lens in the first mode, when it is assumed that the refractive index and the Abbe constant of the positive lens arranged in the middle of the triplet in the second group optical system G2 are respectively  $N_{c2}$  and  $v_{c2}$ , the following conditional expressions are satisfied.

$$1.70 < N_{c2} < 1.90 \quad (11)$$

$$20 < v_{c2} < 40 \quad (12)$$

The zoom lens according to the fifth mode is such that, in the zoom lens in the fourth mode, when it is assumed that the refractive

index and the Abbe constant of the negative lens arranged closest to the object side of the triplet in the second group optical system G2 are respectively  $N_{c1}$  and  $v_{c1}$ , and the refractive index and the Abbe constant of the negative lens arranged closest to the image surface side of the triplet in the second group optical system G2 are respectively  $N_{c3}$  and  $v_{c3}$ , the following conditional expressions are satisfied.

$$N_{c1} < 1.62 \quad (13)$$

$$55 < v_{c1} \quad (14)$$

$$1.65 < N_{c3} \quad (15)$$

$$v_{c3} < 40 \quad (16)$$

The zoom lens according to the sixth mode is such that, in the zoom lens in the first mode, when it is assumed that a radius of curvature of a cementing surface on the object side of the triplet in the second group optical system G2 is  $R_{c2}$ , and a radius of curvature of a surface closest to the image surface side of the triplet in the second group optical system is  $R_{c4}$ , the following conditional expression is satisfied.

$$0.2 < (R_{c2}/R_{c4}) < 0.4 \quad (17)$$

The zoom lens according to the seventh mode is such that, in the zoom lens in the first mode, the surface closest to the object side in the second group optical system is aspherical.

In the zoom lens formed of five groups of positive-negative-positive-positive-positive, such as the zoom lens according to the fifth embodiment, generally, the second group optical system G2 monotonously moves from the object side to the image

surface side, accompanying zooming from the short focal-length side toward the long focal-length side, and the fourth group optical system G4 moves so as to correct a change in the image surface position accompanying zooming. The zooming function is the responsibility of the second group optical system G2, and the fifth group optical system G5 is mainly provided for keeping an exit pupil from the image surface.

In such a zoom lens, in order to further reduce the size, it is necessary to strengthen the power of the respective group optical systems, particularly, the power of the second group optical system G2, being a zooming group. Therefore, in the second group optical system G2, excellent correction of aberrations should be performed. In the zoom lens according to the fifth embodiment, the second group optical system G2 has a configuration including a triplet including a negative lens, a positive lens, and a negative lens, in order to perform excellent correction of aberrations. The two cementing surfaces have different distances from the diaphragm, and the ways of passage of the on-axis and off-axis beams are also different. The on-axis chromatic aberration and the chromatic aberration of magnification can be corrected independently to some extent, by such two cementing surfaces, and as a result, it is effective for correction of chromatic aberration of magnification, which increases with achievement of a wide angle of view. As a method of providing two cementing surfaces, it can be considered to use two sets of cemented lenses, but when the optical axes of the two cemented lenses are deviated from each other, due to a deviation at the time of assembly, chromatic aberration of magnification

occurs asymmetrically off the axis, and as a result, unnatural color blur is likely to occur. On the other hand, when the triplet is used as in the present invention, a deviation at the time of assembly does not occur on the two cementing surfaces, and hence, a product in which chromatic  
5 aberration of magnification is reduced sufficiently can be manufactured.

In the zoom lens according to the fifth embodiment, in order to perform more sufficient correction of aberrations, as described above, it is desired that the negative lens arranged closest to the object side of the triplet in the second group optical system G2 be a double-concave  
10 lens. Particularly, the surface on the image surface side of the negative lens is made a strong concave, so as to mainly perform correction of spherical aberration and comatic aberration.

In order to perform more sufficient correction of aberrations, it is desired that the negative lens arranged closest to the image surface  
15 side of the triplet in the second group optical system G2 has a strong concave facing the image surface side. The surface on the image surface side of the negative lens is made a strong concave, so as to perform secondary correction of spherical aberration and comatic aberration, and also contribute to the correction of astigmatism.

20 In order to perform excellent correction of chromatic aberration, it is desired that the conditional expressions (11)  $1.70 < N_{c2} < 1.90$  and (12)  $20 < v_{c2} < 40$  be satisfied. If the refractive index  $N_{c2}$  of the positive lens arranged in the middle of the triplet in the second group optical system G2 is not smaller than 1.90, and the Abbe constant  $v_{c2}$  of the  
25 positive lens is not larger than 20, it becomes difficult to balance the

on-axis chromatic aberration against other aberrations, and particularly, the on-axis chromatic aberration at the long focal-length side is likely to occur. Further, the correction effect of monochromatic aberration on the cementing surface on the object side cannot be sufficiently  
5 obtained.

On the other hand, if the refractive index  $N_{c2}$  is not larger than 1.7, and the Abbe constant  $v_{c2}$  is not smaller than 40, it is advantageous in view of the correction of aberrations, but such a glass material is expensive, thereby causing an unnecessary cost increase.

10 Further, in order to favorably correct the chromatic aberration of magnification, it is desired to satisfy the conditional expressions (13)  $N_{c1} < 1.62$ , (14)  $v_{c1} > 55$ , (15)  $N_{c3} > 1.65$ , and (16)  $v_{c3} < 40$ . By satisfying the conditional expressions (13) to (16) relating to the refractive index  $N_{c1}$  and the Abbe constant  $v_{c1}$  of the negative lens arranged closest to  
15 the object side of the triplet, and the refractive index  $N_{c3}$  and the Abbe constant  $v_{c3}$  of the negative lens arranged closest to the image surface side of the triplet in the second group optical system G2, as well as the conditional expressions (11) and (12) relating to the refractive index  $N_{c2}$  and the Abbe constant  $v_{c2}$  of the positive lens arranged in the middle of  
20 the triplet in the second group optical system G2, the on-axis chromatic aberration can be balanced against the chromatic aberration of magnification, and particularly, the chromatic aberration of magnification at the short focal-length side can be reduced.

At this time, the correction state of the monochromatic  
25 aberration can be also maintained favorably.

In order to further improve the monochromatic aberration, it is desired to satisfy the conditional expression (17),  $0.2 < (R_{c2}/R_{c4}) < 0.4$ . When a ratio ( $R_{c2}/R_{c4}$ ) between a radius of curvature  $R_{c2}$  of the cementing surface on the object side and a radius of curvature  $R_{c4}$  of the surface closest to the image surface side, of the triplet in the second group optical system G2, becomes not smaller than 0.5, spherical aberration at the long focal-length side is likely to occur largely in the positive direction, thereby causing deterioration in the image contrast. On the other hand, when the ratio ( $R_{c2}/R_{c4}$ ) is not larger than 0.1, the correction ability of astigmatism and curvature of field becomes insufficient, thereby causing deterioration in the flatness on the image surface in the whole area of the zooming range.

In order to make the zoom lens of the present invention more simple and high performance, it is desired that the surface on the object side be an aspheric surface at least on the lens closest to the object side in the second group optical system G2. Since the surface closest to the object side in the second group optical system G2 is relatively close to the diaphragm FA arranged on the object side of the third group optical system G3, a change in the beam height due to zooming is small, in addition to that the marginal beam has a sufficient height. As a result, by providing an aspheric surface here, spherical aberration, being the standard of imaging performance, can be corrected more favorably.

According to the second and the third modes of the zoom lens of the fifth embodiment, since high-performance zoom lens can be

provided in which various aberrations are corrected more favorably, a higher quality camera and a higher quality mobile information terminal can be realized.

According to the fourth mode of the zoom lens of the fifth  
5 embodiment, a high performance zoom lens in which mainly on-axis chromatic aberration is corrected more favorably can be provided. As a result, a higher quality camera and a higher quality mobile information terminal can be realized.

According to the fifth mode of the zoom lens of the fifth  
10 embodiment, a high performance zoom lens in which mainly chromatic aberration of magnification is corrected more favorably can be provided. As a result, a higher quality camera and a higher quality mobile information terminal can be realized.

According to the sixth mode of the zoom lens of the fifth  
15 embodiment, a high performance zoom lens in which mainly monochromatic aberration is corrected more favorably can be provided. As a result, a higher quality camera and a higher quality mobile information terminal can be realized.

According to the seventh mode of the zoom lens of the fifth  
20 embodiment, a high performance zoom lens in which mainly spherical aberration is corrected more favorably can be provided. As a result, a higher quality camera and a higher quality mobile information terminal can be realized.

A sixth embodiment of the present invention explains the zoom  
25 lens according to the present invention. A fundamental configuration



of the zoom lens according to the sixth embodiment is explained first, followed by a specific configuration of this zoom lens is explained in detail, with reference to the block diagram of the optical system illustrated in Fig. 59 to Fig. 74, while enumerating specific numerical  
5 examples as example 4-1 to example 4-1.

The zoom lens according to the sixth embodiment includes a first group optical system G1 having a positive focal length, a second group optical system G2 having a negative focal length, a third group optical system G3 having a positive focal length, a fourth group optical  
10 system having a positive focal length, and a fifth group optical system having a positive focal length, arranged in order from the object side to the image surface side. A diaphragm FA is provided on the object side of the third group optical system G3, and at least the second group optical system G2 and the fourth group optical system G4 move  
15 accompanying zooming from the short focal-length side toward the long focal-length side. Further, the zoom lens is formed in various modes having features described below. The zoom lens according to the first mode is such that the second group optical system G2 includes a triplet including a negative lens, a positive lens, and a negative lens in order  
20 from the object side toward the image surface side. The zoom lens according to the second mode is such that, in the zoom lens in the first mode, the negative lens arranged closest to the object side of the triplet in the second group optical system G2 is a double-concave lens.

The zoom lens according to the third mode is such that, in the  
25 zoom lens in the first mode, the negative lens arranged closest to the

image surface side of the triplet in the second group optical system G2 is a double-concave lens. The zoom lens according to the fourth mode is such that, in the zoom lens in the first mode, when it is assumed that the refractive index and the Abbe constant of the positive lens arranged in the middle of the triplet in the second group optical system G2 is respectively  $N_{c2}$  and  $v_{c2}$ , the following conditional expressions are satisfied.

$$1.70 < N_{c2} < 1.90 \quad (18)$$

$$20 < v_{c2} < 40 \quad (19)$$

The zoom lens according to the fifth mode is such that, in the zoom lens in the fourth mode, when it is assumed that the refractive index and the Abbe constant of the negative lens arranged closest to the object side of the triplet in the second group optical system G2 are respectively  $N_{c1}$  and  $v_{c1}$ , and the refractive index and the Abbe constant of the negative lens arranged closest to the image surface side of the triplet in the second group optical system G2 are respectively  $N_{c3}$  and  $v_{c3}$ , the following conditional expressions are satisfied.

$$N_{c1} < 1.62 \quad (20)$$

$$v_{c1} > 55 \quad (21)$$

$$N_{c3} > 1.65 \quad (22)$$

$$v_{c3} < 40 \quad (23)$$

The zoom lens according to the sixth mode is such that, in the zoom lens in the first mode, when it is assumed that a radius of curvature of a cementing surface on the object side of the triplet in the second group optical system G2 is  $R_{c2}$ , and a radius of curvature of a

surface closest to the image surface side of the triplet in the second group optical system G2 is  $R_{c4}$ , the following conditional expression is satisfied.

$$0.2 < (R_{c2}/R_{c4}) < 0.4 \quad (24)$$

5        The zoom lens according to the seventh mode is such that, in the zoom lens in the first mode, the surface closest to the object side in the group optical system G2 is an aspheric surface.

         In the zoom lens including five groups of positive-negative-positive-positive-positive, like the zoom lens  
10 according to the sixth embodiment, generally, the second G2 moves monotonously from the object side to the image surface side, accompanying zooming from the short focal-length side to the long focal-length side, and the fourth group optical system G4 moves so as to correct a change in the image surface position accompanying  
15 zooming. The zooming function is the responsibility of the second group optical system G2, and the fifth group optical system G5 is mainly provided for keeping an exit pupil from the image surface.

         In such a zoom lens, in order to further reduce the size, it is necessary to strengthen the power of the respective group optical  
20 systems, particularly, the power of the second group optical system G2, being a zooming group. Therefore, in the second group optical system G2, excellent correction of aberrations should be performed. In the zoom lens according to the sixth embodiment, the second group optical system G2 has a configuration including a triplet including a negative  
25 lens, a positive lens, and a negative lens, in order to perform excellent

correction of aberrations. The two cementing surfaces have different distances from the diaphragm, and the ways of passage of the beams on the axis and off the axis are also different. The on-axis chromatic aberration and the chromatic aberration of magnification can be

5 corrected independently to some extent, by such two cementing surfaces, and as a result, it is also effective for correction of chromatic aberration of magnification, which increases with achievement of a wide angle of view. As a method of providing two cementing surfaces, it can be considered to use two sets of cemented lenses, but when the optical

10 axes of the two cemented lenses are deviated from each other, due to a deviation at the time of assembly, chromatic aberration of magnification occurs asymmetrically off the axis, and as a result, unnatural color blur is likely to occur. On the other hand, when the triplet is used as in the present invention, a deviation at the time of assembly does not occur on

15 the two cementing surfaces, and hence, a product in which chromatic aberration of magnification is reduced sufficiently can be manufactured.

In the zoom lens according to the sixth embodiment, in order to perform correction of aberrations more sufficiently, it is desired that the negative lens arranged closest to the object side of the triplet in the

20 second group optical system G2 is a double-concave lens. The surface of the negative lens, particularly, the surface on the image surface side is a strong concave, so as to mainly perform correction of spherical aberration and comatic aberration. In order to perform aberration correction more sufficiently, it is desired that the negative

25 lens arranged closest to the image surface side of the triplet in the

second group optical system G2 is a double-concave lens. The surface of the negative lens on the image surface side is a strong concave, so as to perform secondary correction of spherical aberration and comatic aberration, and also contribute to the correction of  
5 astigmatism.

In order to perform excellent correction of chromatic aberration, it is desired that the conditional expressions (18)  $1.70 < N_{c2} < 1.90$  and (19)  $20 < v_{c2} < 40$  be satisfied. If the refractive index  $N_{c2}$  of the positive lens arranged in the middle of the triplet in the second group optical  
10 system G2 is not smaller than 1.90, and the Abbe constant  $v_{c2}$  of the positive lens is not larger than 20, it becomes difficult to balance the on-axis chromatic aberration against other aberrations, and particularly, the on-axis chromatic aberration at the long focal-length side is likely to occur. Further, the correction effect of monochromatic aberration on  
15 the cementing surface on the object side cannot be sufficiently obtained. On the other hand, if the refractive index  $N_{c2}$  is not larger than 1.7, and the Abbe constant  $v_{c2}$  is not smaller than 40, it is advantageous in view of the correction of aberrations, but such a glass material is expensive, thereby causing an unnecessary cost increase.

20 Further, in order to favorably correct the chromatic aberration of magnification, it is desired to satisfy the conditional expressions (20)  $N_{c1} < 1.62$ , (21)  $v_{c1} > 55$ , (22)  $N_{c3} > 1.65$ , and (23)  $v_{c3} < 40$ . By satisfying the conditional expressions (20) to (23) relating to the refractive index  $N_{c1}$  and the Abbe constant  $v_{c1}$  of the negative lens arranged closest to  
25 the object side of the triplet, and the refractive index  $N_{c3}$  and the Abbe

constant  $v_{c3}$  of the negative lens arranged closest to the image surface side of the triplet in the second group optical system G2, as well as the conditional expressions (18) and (19) relating to the refractive index  $N_{c2}$  and the Abbe constant  $v_{c2}$  of the positive lens arranged in the middle of the triplet in the second group optical system G2, the on-axis chromatic aberration can be balanced against the chromatic aberration of magnification, and particularly, the chromatic aberration of magnification at the short focal-length side can be reduced.

At this time, the correction state of the monochromatic aberration can be also maintained favorably. In order to further improve the monochromatic aberration, it is desired to satisfy the conditional expression (24),  $0.2 < (R_{c2}/R_{c4}) < 0.4$ . When a ratio  $(R_{c2}/R_{c4})$  between a radius of curvature  $R_{c2}$  of the cementing surface on the object side and a radius of curvature  $R_{c4}$  of the surface closest to the image surface side, of the triplet in the second group optical system G2, becomes not smaller than 0.5, spherical aberration at the long focal-length side is likely to occur largely in the positive direction, thereby causing deterioration in the image contrast. On the other hand, when the ratio  $(R_{c2}/R_{c4})$  is not larger than 0.1, the correction ability of astigmatism and curvature of field becomes insufficient, thereby causing deterioration in the flatness on the image surface in the whole area of the zooming range.

In order to make the zoom lens of the present invention more simple and high performance, it is desired that the surface on the object side be an aspheric surface at least on the lens closest to the object

side in the second group optical system G2. Since the surface closest to the object side in the second group optical system G2 is relatively close to the diaphragm FA arranged on the object side of the third group optical system G3, a change in the beam height due to zooming is small, in addition to that the marginal beam has a sufficient height. As a result, by providing an aspheric surface here, spherical aberration, being the standard of imaging performance, can be corrected more favorably.

Therefore, enumeration of advantages in the camera or the mobile information terminal associated with the zoom lens according to the sixth embodiment of the present invention is as follows.

According to the first mode of the zoom lens of the sixth embodiment, a zoom lens having a resolving power corresponding to the image capturing device with 3,000,000 to 5,000,000 pixels can be provided. As a result, a camera and a mobile information terminal of a small size, which can obtain high magnification and high quality, can be realized.

According to the second and the third modes of the zoom lens of the sixth embodiment, since a high-performance zoom lens in which various aberrations are favorably corrected can be provided, a camera and a mobile information terminal having a higher quality can be realized.

According to the fourth mode of the zoom lens of the sixth embodiment, since a high-performance zoom lens in which mainly on-axis chromatic aberration is more favorably corrected can be

provided, a camera and a mobile information terminal having a higher quality can be realized.

According to the fifth mode of the zoom lens of the sixth embodiment, since a high-performance zoom lens in which mainly  
5 chromatic aberration of magnification is more favorably corrected can be provided, a camera and a mobile information terminal having a higher quality can be realized.

According to the sixth mode of the zoom lens of the sixth embodiment, since a high-performance zoom lens in which mainly  
10 monochromatic aberration is more favorably corrected can be provided, a camera and a mobile information terminal having a higher quality can be realized.

According to the seventh mode of the zoom lens of the sixth embodiment, since a high-performance zoom lens in which mainly  
15 spherical aberration is more favorably corrected can be provided, a camera and a mobile information terminal having a higher quality can be realized.

A camera according to a seventh embodiment of the present invention uses the zoom lens according to the fourth to the sixth  
20 embodiments as the shooting optical system. A mobile information terminal according to the seventh embodiment uses the zoom lens according to the fifth embodiment as the shooting optical system in its camera unit.

A first mode of the seventh embodiment, in which the camera is  
25 constructed by adopting the zoom lens as shown in the fifth



embodiment as the shooting optical system, will be explained with reference to Fig. 75 to Fig. 77. Fig. 75 is a perspective view of a camera according to a first mode of a seventh embodiment of the present invention, with a shooting lens retracted in the camera body  
5 seen from an object side. Fig. 76 is a perspective view of the camera according to the first mode of the seventh embodiment, with the shooting lens extended from the camera body seen from the object side. Fig. 77 is a perspective view of the camera shown in Fig. 75, seen from a photographer side.

10 A second mode of the seventh embodiment, in which a camera is constructed by adopting the zoom lens as shown in the fifth embodiment as the shooting optical system will be explained with reference to Fig. 78 to Fig. 80. Fig. 78 is a perspective view of a camera according to a second mode of the seventh embodiment, with a  
15 shooting lens retracted in the camera body seen from an object side. Fig. 79 is a perspective view of the camera according to the second mode of the seventh embodiment, with the shooting lens extended from the camera body seen from the object side. Fig. 80 is a perspective view of the camera shown in Fig. 78, seen from a photographer side.

20 A camera is explained here as an example, however, devices in which the camera function is incorporated in a mobile information terminal such as a so-called personal data assistant (PDA) and a mobile phone are in market recently. Such a mobile information terminal includes substantially the same function and configuration as  
25 those of the camera, though the appearance is slightly different. Such

a mobile information terminal may be realized by the second mode in the seventh embodiment of the present invention, in which the zoom lens according to the fourth to the sixth embodiments is used.

As illustrated in Fig. 75 to Fig. 80, the camera includes a shooting lens 101, a shutter button 102, a zoom lever 103, a finder 104, a strobe 105, a liquid crystal monitor 106, operation buttons 107, a power switch 108, a memory card/communication card slot 109, and the like.

Fig. 81 is a block diagram of the camera according to the seventh embodiment. The camera includes a photodetector 201, a signal processor 202, an image processor 203, a CPU 204, a semiconductor memory 205, and a communication card 206.

The camera has the shooting lens 101 and the photodetector 201 as an area sensor such as a CCD image capturing device, and is constructed such that an image of an object, being an object to be photographed, that is, the image of the subject formed by the shooting lens 101, being the shooting optical system, is read by the photodetector 201. For the shooting lens 101, the zoom lens explained in the fifth embodiment is used.

The output of the photodetector 201 is processed by the signal processor 202 controlled by the CPU 204, and converted into digital image information. The image information digitalized by the signal processor 202 is subjected to predetermined image processing in the image processor 203 controlled by the CPU 204, and thereafter, recorded in the semiconductor memory 205 such as a nonvolatile

memory. In this case, the semiconductor memory 205 may be a memory card loaded in the memory card/communication card slot 109, or a semiconductor memory built in the camera body. The image being photographed can be displayed on the liquid crystal monitor 104, or the  
5 image recorded in the semiconductor memory 205 can be displayed thereon. The image recorded in the semiconductor memory 205 can be also transmitted to external equipment via the communication card 206 or the like loaded in the memory card/communication card slot 109.

The shooting lens 101 is buried in the camera body, at the time  
10 of carrying the camera, as illustrated in Fig. 75, and when a user operates the power switch 108 to turn on the power, the body tube is let out as illustrated in Fig. 76, and protruded from the camera body. At this time, inside of the body tube of the shooting lens 101, the optical system in each group constituting the zoom lens has the arrangement,  
15 for example, at the short focal-length side, and by operating the zoom lever 103, the arrangement of the respective group optical systems is changed, thereby enabling the zooming operation toward the long focal-length side. Preferably, the finder 104 is also zoomed, linked with a change in the angle of view of the shooting lens 101.

20 In many cases, focusing is performed by half-pressing the shutter button 102. Focusing in the zoom lens constituted of five groups of positive-negative-positive-positive-positive as shown in the fifth embodiment can be performed by the movement of the fifth group optical system G5 or by the movement of the photodetector 201.  
25 When the shutter button 102 is further pressed to the fully pressed state,

shooting is performed, and thereafter, the processing as described above is performed.

When the image recorded in the semiconductor memory 205 is displayed on the liquid crystal monitor 106, or transmitted to the external equipment via the communication card 206 or the like, the operation button 107 is operated in a predetermined manner. The semiconductor memory 205 and the communication card 206 are loaded in a respectively dedicated slot or a general-purpose slot equipped in the memory card/communication card slot 109 or the like and used.

The zoom lens as shown in the fifth embodiment can be used as the shooting optical system in the camera or the mobile information terminal. Therefore, a camera or a mobile information terminal, which is small and high quality, and uses a photodetector of a class of 3,000,000 to 5,000,000 pixels, can be achieved. Therefore, advantages in the camera or the mobile information terminal associated with the zoom lens according to the fifth and the seventh embodiments of the present invention are as follows.

According to the first mode of the zoom lens of the fifth embodiment, a zoom lens having a resolving power corresponding to the image capturing device with 3,000,000 to 5,000,000 pixels can be provided. As a result, a camera and a mobile information terminal of a small size, which can obtain a high magnification and high quality, can be realized.

According to the camera in the first mode of the seventh

embodiment of the present invention, a camera that is small and can achieve a high magnification and high performance can be provided, by using the zoom lens having a resolving power corresponding to the image capturing device with 3,000,000 to 5,000,000 pixels, which is sufficiently small and efficient, while being capable of obtaining a high magnification, as the shooting optical system. As a result, users can take pictures of high quality with a camera excellent in portability.

According to the mobile information terminal in the second mode of the seventh embodiment of the present invention, a mobile information terminal that is small and can achieve a high magnification and high quality can be provided, by using the zoom lens having a resolving power corresponding to the image capturing device with 3,000,000 to 5,000,000 pixels, which is sufficiently small and efficient, while being capable of obtaining a high magnification, as the shooting optical system in the camera unit. As a result, users can take pictures of high quality with a mobile information terminal excellent in portability, and transmit the image to external equipment. Since the optical system in the zoom lens of the present invention corresponding to the fifth embodiment, and according to the respective examples explained below can be formed of an optical glass, which is chemically stable and does not contain any toxic substance such as lead or arsenic, the materials can be recycled, and hence conservation of global environment is possible, without having water pollution due to waste fluid at the time of machining.

Example 1 to example 4 for illustrating specific numerical

configurations of the zoom lens according to the first embodiment and the fourth to the sixth embodiments of the present invention will be explained in detail.

Specific configuration and numerical example is shown in  
5 example 1, as an example of the zoom lens according to the first  
embodiment of the present invention. In example 1, the aberrations of  
the zoom lens are sufficiently corrected, and correspondence to the  
photodetector with 3,000,000 to 5,000,000 pixels becomes possible. It  
will be obvious from the examples below, that excellent imaging  
10 performance can be ensured, while achieving sufficient miniaturization  
and a wide angle of view, by forming the zoom lens as shown in the first  
embodiment.

In example 1, various signs are used as described below.

R: radius of curvature of each surface

15 D: spacing

$N_d$ : refracting power with respect to d ray

$v_d$ : Abbe constant with respect to d ray

f: combined focal length of the whole system

F: F number

20  $\omega$ : half angle of view

y': image height

Wide: wide angle, short focal-length side

Mean: means focal length

Tele: telephoto, long focal-length side

25 Further, in order to define an aspheric surface, following signs

are used.

Y: height from the optical axis

R: paraxial radius of curvature of the aspheric surface

K: conical multiplier

5         $A_4$ : fourth coefficient of the aspheric surface

$A_6$ : sixth coefficient of the aspheric surface

$A_8$ : eighth coefficient of the aspheric surface

$A_{10}$ : tenth coefficient of the aspheric surface

SQRT: square root

10        That is, the aspheric surface is expressed by the following expression, as a distance X from a tangent plane at an apex of the aspheric surface at a height Y from the optical axis.

$$X = \frac{(1/R) \times Y^2}{1 + \text{SQRT} \{1 - (1+K) \times (Y/R)^2\}} + A_4 \times Y^4 + A_6 \times Y^6 + A_8 \times Y^8 + A_{10} \times Y^{10} \quad (25)$$

15        In the numerical example described below, E-XY stands for  $10^{-XY}$ . Further, in the aberration diagram explained below, a solid line expresses spherical aberration, a broken line expresses a sine condition in the spherical aberration, and in astigmatism, a solid line expresses a sagittal image surface, and a broken line expresses a meridional image surface. Further, one solid line denotes d ray (587.56 nm), and the other solid line denotes g ray (435.83 nm).

20

Fig. 1 is a schematic diagram of an optical system of example 1-1 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens

E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a diaphragm FA, and an optical filter (including a cover glass) OF. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the sixth lenses E4 to E6 constitute the second group optical system G2, and the seventh to the eleventh lenses E7 to E11 constitute the third group optical system G3.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. The diaphragm FA is arranged on the object side of the third group optical system G3, and operates integrally with the third group optical system G3. Surface numbers of the respective optical surfaces are added for reference. The respective reference signs in Fig. 1 are used independently for each example, in order to avoid complexity due to an increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common configuration to other examples:

For example, the first lens E1, the second lens E2, the third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the diaphragm FA, the seventh lens E7, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, and the optical filter OF are arranged in order from the object side of a subject or the like, and an image is formed at the back of the optical filter OF having various optical filtering functions.



The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3 is a positive meniscus lens formed in a convex shape on the object side.

- 5 The first lens E1 and the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

- The fourth lens E4 is a negative meniscus lens formed in a convex shape on the object side, the fifth lens E5 is a negative lens including a double-concave lens, and the sixth lens E6 is a positive meniscus lens formed in a convex shape on the object side. The fifth lens E5 and the sixth lens E6 form a densely cemented doublet, and the second group optical system G2 formed of the fourth to the sixth lenses E4 to E6 exhibits a negative focal length as a whole. The seventh lens
- 15 E7 is a positive lens including a double-convex lens, the eighth lens E8 is a negative meniscus lens formed in a convex shape on the object side, the ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a negative lens including a double-concave lens, and the eleventh lens E11 is a positive lens including a double-convex
- 20 lens. The eighth to the tenth lenses E8 to E10 form a densely cemented triplet, and the third group optical system G3 formed of the seventh to the eleventh lenses E7 to E11 exhibits a positive focal length as a whole. The diaphragm FA arranged between the second group optical system G2 and the third group optical system G3 operates
- 25 integrally with the third group optical system G3, and the distance from

the third group optical system G3 is constant.

The optical filter OF arranged on the image surface side of the eleventh lens E11 in the third group optical system G3 may include a cover glass of a solid image capturing device 53 such as a CCD image capturing device, and has various optical filtering functions. In this example 1-1, the sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second group optical system G2, and the twelfth surface, being a surface on the object side of the seventh lens E7 located closest to the object side in the third group optical system G3 are respectively aspheric surfaces.

The shift of the respective group optical systems G1 to G3 accompanying zooming between the wide-angle end, that is, the short focal-length side, and the telephoto end, that is, the long focal-length side is, as illustrated in Fig. 1, such that the second group optical system G2 is fixed with respect to the image surface without shift, the first group optical system G1 shifts from the image surface side toward the object side, and the third group optical system G3 also shifts from the image surface side toward the object side, with a shift from the short focal-length side to the long focal-length side. In example 1-1, the focal length  $f$  of the whole system, the F number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=5.902$  to  $17.707$ ,  $F=3.37$  to  $4.41$ , and  $\omega=38.2$  to  $14.7$ . The optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table. The lens surface added with \* are aspheric surfaces.

**Table1** Optical characteristics

Sur-face	R	D	N d	$\nu$ d	Note
1	52.282	1.000	1.84666	23.8	First lens
2	28.671	2.898	1.48749	70.4	Second lens
3	174.021	0.100			
4	24.552	2.568	1.72916	54.7	Third lens
5	99.447	d 1			
6*	17.989	0.800	1.88300	40.8	Fourth lens
7	4.910	4.778			
8	-9.828	0.800	1.58313	59.5	Fifth lens
9	7.598	1.483	1.80518	25.5	Sixth lens
10	1630.729	d 2			
11	0.000	0.100			
12*	10.680	3.012	1.51680	64.2	Seventh lens
13	-8.429	1.837			
14	41.562	0.800	1.84666	23.8	Eighth lens
15	13.393	2.091	1.74950	35.0	Ninth lens
16	-3.828	0.800	1.68893	31.2	Tenth lens
17	5.954	0.991			
18	8.271	2.061	1.49700	81.6	Eleventh lens
19	-13.509	d 3			
20	0.000	1.980	1.51680	64.2	Filter, cover glass
21	0.000				

The optical surfaces on the sixth and the twelfth surfaces in Table 1 are aspheric surfaces, and parameters relating to expression (25) on the respective aspheric surfaces are as shown in the following

table.

**Table2** Coefficient of aspheric surface

Sur-face	K	$A_4$	$A_6$	$A_8$	$A_{10}$
6	-2.73185	1.43332E-04	-3.96660E-06	1.13380E-07	-1.45326E-09
12	-3.57231	-5.64058E-04	-1.78799E-05	2.26160E-06	-2.09146E-07

The interval d1 between the first group optical system G1 and the second group optical system G2, the interval d2 between the second group optical system G2 and the diaphragm FA, and the interval d3 between the third group optical system G3 and the optical filter OF are variable, and these variable intervals d1, d2, and d3 are changed as shown in the following table, corresponding to the focal length f of the whole system, accompanying zooming.

**Table3** Variable intervals

	f	d 1	d 2	d 3
Wide	5.902	1.000	7.680	7.877
Mean	10.688	2.377	2.188	13.362
Tele	17.707	12.868	1.002	14.538

10

The parameter values according to the respective conditional expressions (1) to (3) of the present invention in example 1-1 are as shown in the following table, and within the range of the respective conditional expressions.

**Table4** Parameter values in conditional expressions

$N_p - N_n$	-0.018
$v_p - v_n$	7.57
$K_{12} / (f_w + f_t)$	0.715

The aberration diagram in example 1-1 is illustrated in Fig. 8.

Fig. 2 is a schematic diagram of an optical system of example 1-2 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a diaphragm FA, and an optical filter (including a cover glass) OF. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the sixth lenses E4 to E6 constitute the second group optical system G2, and the seventh to the eleventh lenses E7 to E11 constitute the third group optical system G3.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. The diaphragm FA is arranged on the object side of the third group optical system G3, and operates integrally with the third group optical system G3. Surface numbers of the respective optical surfaces are added for reference. The respective reference signs in Fig. 2 are used

independently for each example, in order to avoid complexity due to an increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

5           For example, the first lens E1, the second lens E2, the third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the diaphragm FA, the seventh lens E7, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, and the optical filter OF are arranged in order from the object side of a subject or the like, and  
10   an image is formed at the back of the optical filter OF having various optical filtering functions.

          The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3  
15   is a positive meniscus lens formed in a convex shape on the object side. The first lens E1 and the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

          The fourth lens E4 is a negative meniscus lens formed in a  
20   convex shape on the object side, the fifth lens E5 is a negative lens including a double-concave lens, and the sixth lens E6 is a positive lens including a double-convex lens. The fifth lens E5 and the sixth lens E6 form a densely cemented doublet, and the second group optical system G2 formed of the fourth to the sixth lenses E4 to E6 exhibits a negative  
25   focal length as a whole. The seventh lens E7 is a positive lens

including a double-convex lens, the eighth lens E8 is a negative lens  
including a double-concave lens, the ninth lens E9 is a positive lens  
including a double-convex lens, the tenth lens E10 is a negative lens  
including a double-concave lens, and the eleventh lens E11 is a positive  
5 lens including a double-convex lens. The eighth to the tenth lenses E8  
to E10 form a densely cemented triplet, and the third group optical  
system G3 formed of the seventh to the eleventh lenses E7 to E11  
exhibits a positive focal length as a whole. The diaphragm FA  
arranged between the second group optical system G2 and the third  
10 group optical system G3 operates integrally with the third group optical  
system G3, and the distance from the third group optical system G3 is  
constant.

The optical filter OF arranged on the image surface side of the  
eleventh lens E11 in the third group optical system G3 may include a  
15 cover glass of a solid image capturing device 53 such as a CCD image  
capturing device, and has various optical filtering functions.

In this example 1-2, the fifth surface, being a surface on the  
image surface side of the third lens E3 located closest to the image  
surface side in the first group optical system G1, and the twelfth surface,  
20 being a surface on the object side of the seventh lens E7 located  
closest to the object side in the third group optical system G3, and the  
eighteenth surface, being a surface on the object side of the eleventh  
lens E11 located closest to the image surface side in the third group  
optical system G3 are respectively aspheric surfaces.

25 The shift of the respective group optical systems G1 to G3

accompanying zooming between the wide-angle end, that is, the short focal-length side, and the telephoto end, that is, the long focal-length side is, as illustrated in Fig. 2, such that the first group optical system G1 shifts with from the object side toward the image surface with a shift  
5 from the intermediate focal-length side to the long focal-length side, and the second group optical system G2 shifts from the object side toward the image surface side with a shift from the short focal-length side to the long focal-length side, and the third group optical system G3 also shifts from the image surface side toward the object side, with a shift from the  
10 short focal-length side to the long focal-length side.

In example 1-2, the focal length  $f$  of the whole system, the  $F$  number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=5.081$  to  $15.307$ ,  $F=2.87$  to  $3.53$ , and  $\omega=42.5$  to  $16.9$ . The optical characteristics relating to the respective optical surfaces and the  
15 optical elements are as shown in the following table. The lens surface added with \* are aspheric surfaces.



**Table5** Optical characteristics

Sur-face	R	D	N d	$\nu$ d	Note
1	29.023	0.800	1.84666	23.8	First lens
2	22.712	1.757	1.49700	81.6	Second lens
3	24.448	0.141			
4	24.399	3.354	1.72916	54.7	Third lens
5*	100.352	d 1			
6	92.631	0.800	1.83500	40.8	Fourth lens
7	6.089	4.846			
8	-13.244	0.800	1.51680	64.2	Fifth lens
9	9.018	3.524	1.70200	33.3	Sixth lens
10	-25.662	d 2			
11	0.000	0.100			
12	7.653	1.853	1.69680	55.5	Seventh lens
13	-78.558	2.720			
14	-49.283	0.800	1.83400	43.0	Eighth lens
15	5.245	1.970	1.77250	55.5	Ninth lens
16	-6.596	0.800	1.75520	33.3	Tenth lens
17	2508.659	6.154			
18*	33.022	1.400	1.64769	81.6	Eleventh lens
19	-63.392	d 3			
20	0.000	1.980	1.51680	64.2	Filter, cover glass
21	0.000				

The optical surfaces on the fifth, the twelfth surfaces, and the eighteenth surfaces in Table 5 are aspheric surfaces, and parameters relating to expression (25) on the respective aspheric surfaces are as

shown in the following table.

**Table6** Coefficient of aspheric surface

Sur-face	K	A <sub>4</sub>	A <sub>6</sub>	A <sub>8</sub>	A <sub>10</sub>
5	5.1558	1.09142E-04	-7.88649E-07	6.95776E-09	-2.88606E-11
12	0.5678	-2.72169E-04	-6.04473E-06	1.38190E-07	-1.47112E-08
18	-109722.6	7.20399E-04	1.32008E-05	7.50297E-07	-2.83837E-08

The interval d1 between the first group optical system G1 and the second group optical system G2, the interval d2 between the second group optical system G2 and the diaphragm FA, and the interval d3 between the third group optical system G3 and the optical filter OF are variable, and these variable intervals d1, d2, and d3 are changed as shown in the following table, corresponding to the focal length f of the whole system, accompanying zooming.

**Table7** Variable intervals

	f	d 1	d 2	d 3
Wide	5.081	1.000	18.345	1.000
Mean	8.307	6.481	8.179	3.074
Tele	15.307	15.868	0.847	5.883

10

The parameter values according to the respective conditional expressions (1) to (3) of the present invention in example 1-2 are as shown in the following table, and within the range of the respective conditional expressions.

**Table8** Parameter values in conditional expressions

$N_p - N_n$	-0.022
$\nu_p - \nu_n$	17.34
$K_{12} / (f_w + f_t)$	1.111

The aberration diagram in example 1-2 is illustrated in Fig. 9.

Fig. 3 is a schematic diagram of an optical system of example 1-3 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a diaphragm FA, and an optical filter (including a cover glass) OF. In this case, the first lens E1 and the second lens E2 constitute the first group optical system G1, the third lens E3 to the fifth lenses E5 constitute the second group optical system G2, and the sixth lens E6 to the tenth lens E10 constitute the third group optical system G3.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. The diaphragm FA is arranged on the object side of the third group optical system G3, and operates integrally with the third group optical system G3. Surface numbers of the respective optical surfaces are added for reference. The respective reference signs in Fig. 3 are used independently for each example, in order to avoid complexity due to an

increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

In Fig. 3, for example, the first lens E1, the second lens E2, the  
5 third lens E3, the fourth lens E4, the fifth lens E5, the diaphragm FA ,  
the sixth lens E6, the seventh lens E7, the eighth lens E8, the ninth lens  
E9, the tenth lens E10, the eleventh lens E11, and the optical filter OF  
are arranged in order from the object side of a subject or the like, and  
an image is formed at the back of the optical filter OF having various  
10 optical filtering functions.

The first lens E1 is a negative meniscus lens formed in a convex  
shape on the object side, the second lens E2 is a positive meniscus  
lens formed in a convex shape on the object side, the first group optical  
system G1 formed of the first lens E1 and the second lens E2 exhibits a  
15 positive focal length as a whole.

The third lens E3 is a negative meniscus lens formed in a  
convex shape on the object side, the fourth lens E4 is a double-concave  
negative lens and the fifth lens E5 is a positive meniscus lens formed in  
a convex shape on the object side. The fourth lens E4 and the fifth  
20 lens E5 form a densely cemented doublet, and the second group optical  
system G2 formed of the third lens E3 to the fifth E5 exhibits a negative  
focal length as a whole.

The sixth lens E6 is a positive lens including a double-convex  
lens, the seventh lens E7 is a negative meniscus lens formed in a  
25 convex shape on the object side, the eighth lens E8 is a positive lens

including a double-convex lens, the ninth lens E9 is a negative lens including a double-concave lens, and the tenth lens E10 is a positive lens a double-convex lens. The seventh lens E7 to the ninth lens E9 form a densely cemented triplet, and the third group optical system G3  
5 formed of the sixth to the tenth lenses E6 to E10 exhibits a positive focal length as a whole. The diaphragm FA arranged between the second group optical system G2 and the third group optical system G3 operates integrally with the third group optical system G3, and the distance from the third group optical system G3 is constant.

10 The optical filter OF arranged on the image surface side of the tenth lens E10 in the third group optical system G3 may include a cover glass of a solid image capturing device 53 such as a CCD image capturing device, and has various optical filtering functions. In this example 1-3, the fifth surface, being a surface on the object side of the  
15 third lens E3 located closest to the object side in the second group optical system G2, and the eleventh surface, being a surface on the object side of the sixth lens E6 located closest to the object side in the third group optical system G3 are respectively aspheric surfaces.

The shift of the respective group optical systems G1 to G3  
20 accompanying zooming between the wide-angle end, that is, the short focal-length side, and the telephoto end, that is, the long focal-length side is, as illustrated in Fig. 3, such that the first group optical system G1 shifts from the object side toward the image surface side with a shift from the short focal-length side to the intermediate focal length, and  
25 shifts from the image surface side toward the object side with a shift

from the intermediate focal length to the long focal-length side, and the second group optical system G2 shifts from the object side toward the image surface side.

5 In example 1-3, the focal length  $f$  of the whole system, the F number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=5.899$  to  $23.611$ ,  $F=3.14$  to  $3.83$ , and  $\omega=36.7$  to  $10.6$ . The optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table. The lens surface added with \* are aspheric surfaces.

**Table9** Optical characteristics

Sur-face	R	D	N d	$\nu$ d	Note
1	20.366	0.800	1.84666	23.8	First lens
2	14.124	1.967			
3	15.110	4.900	1.72916	54.7	Second lens
4	127.637	d 1			
5*	72.676	0.800	1.88300	40.8	Third lens
6	6.144	3.409			
7	-28.791	0.800	1.49700	81.6	Fourth lens
8	7.631	2.587	1.80610	33.3	Fifth lens
9	53.039	d 2			
10	0.000	0.100			
11*	10.134	1.520	1.69680	55.5	Sixth lens
12	-18.621	1.976			
13	12.892	0.800	1.88300	40.8	Seventh lens
14	4.621	2.422	1.71300	53.9	Eighth lens
15	-4.926	0.800	1.63980	34.6	Ninth lens
16	5.519	5.379			
17	8.661	2.373	1.49700	81.6	Tenth lens
18	-224.285	d 3			
19	0.000	1.980	1.51680	64.2	Filter, cover glass
20	0.000				

The optical surfaces on the fifth and the eleventh surfaces in Table 9 are aspheric surfaces, and parameters relating to expression (25) on the respective aspheric surfaces are as shown in the following table.

**Table10** Coefficient of aspheric surface

	K	$A_4$	$A_6$	$A_8$	$A_{10}$
5	8.90458	4.51607E-05	-9.20589E-07	1.90474E-08	-1.27028E-10
11	-0.30716	-3.20864E-04	-2.23050E-06	1.31015E-07	-1.42853E-08

The interval d1 between the first group optical system G1 and the second group optical system G2, the interval d2 between the second group optical system G2 and the diaphragm FA, and the interval d3 between the third group optical system G3 and the optical filter OF are variable, and these variable intervals d1, d2, and d3 are changed as shown in the following table, corresponding to the focal length f of the whole system, accompanying zooming.

**Table11** Variable intervals

	f	d 1	d 2	d 3
Wide	5.900	1.000	15.971	1.000
Mean	11.300	5.192	6.028	4.335
Tele	23.600	14.380	1.064	5.948

The parameter values according to the respective conditional expressions (1) to (3) of the present invention in example 1-3 are as shown in the following table, and within the range of the respective conditional expressions.



**Table12** Parameter values in conditional expressions

$N_p - N_n$	-0.048
$v_p - v_n$	16.26
$K_{12} / (f_w + f_t)$	0.778

The aberration diagram in example 1-3 is illustrated in Fig. 10.

Fig. 4 is a schematic diagram of an optical system of example 1-4 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a diaphragm FA, and an optical filter (including a cover glass) OF. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the sixth lenses E4 to E6 constitute the second group optical system G2, and the seventh to the eleventh lenses E7 to E11 constitute the third group optical system G3.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. The diaphragm FA is arranged on the object side of the third group optical system G3, and operates integrally with the third group optical system G3. Surface numbers of the respective optical surfaces are added for reference. The respective reference signs in Fig. 4 are used

independently for each example, in order to avoid complexity due to an increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

5           For example, the first lens E1, the second lens E2, the third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the diaphragm FA, the seventh lens E7, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, and the optical filter OF are arranged in order from the object side of a subject or the like, and  
10   an image is formed at the back of the optical filter OF having various optical filtering functions.

          The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3  
15   is a positive meniscus lens formed in a convex shape on the object side. The first lens E1 and the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

          The fourth lens E4 is a negative meniscus lens formed in a  
20   convex shape on the object side, the fifth lens E5 is a negative lens including a double-concave lens, and the sixth lens E6 is a positive meniscus lens formed in a convex shape on the object side. The fifth lens E5 and the sixth lens E6 form a densely cemented doublet, and the second group optical system G2 formed of the fourth to the sixth lenses  
25   E4 to E6 exhibits a negative focal length as a whole.

The seventh lens E7 is a positive lens including a double-convex lens, the eighth lens E8 is a negative meniscus lens formed in a convex shape on the object side, the ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a negative lens including a double-concave lens, and the eleventh lens E11 is a positive lens including a double-convex lens. The eighth to the tenth lenses E8 to E10 form a densely cemented triplet, and the third group optical system G3 formed of the seventh to the eleventh lenses E7 to E11 exhibits a positive focal length as a whole. The diaphragm FA arranged between the second group optical system G2 and the third group optical system G3 operates integrally with the third group optical system G3, and the distance from the third group optical system G3 is constant.

The optical filter OF arranged on the image surface side of the eleventh lens E11 in the third group optical system G3 may include a cover glass of a solid image capturing device 53 such as a CCD image capturing device, and has various optical filtering functions. In this example 2-4, the fourth surface, being a surface on the object side of the third lens E3 located closest to the object side in the first group optical system G1, and the sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second group optical system G3, and the eighteenth surface, being a surface on the object side of the eleventh lens E11 located closest to the object side in the third group optical system G3 are respectively aspheric surfaces.

The shift of the respective group optical systems G1 to G3

accompanying zooming between the wide-angle end, that is, the short focal-length side, and the telephoto end, that is, the long focal-length side is, as illustrated in Fig. 4, such that the first group optical system G1

5           The shift of the respective group optical systems G1 to G3 accompanying zooming between the wide-angle end, that is, the short focal-length side, and the telephoto end, that is, the long focal-length side is, as illustrated in Fig. 4, such that the first group optical system G1 shifts from the object side toward the image surface side with a shift  
10   from the short focal-length side to the intermediate focal length, and shifts from the image surface side toward the object side with a shift from the intermediate focal length to the long focal-length side, and the second group optical system G2 shifts from the object side toward the image surface side with a shift from the short focal-length side to he  
15   long focal-length side, and the third group optical system G3 shifts from the image surface side toward the object side.

          In example 1-4, the focal length  $f$  of the whole system, the  $F$  number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=5.900$  to  $23.600$ ,  $F=3.04$  to  $3.72$ , and  $\omega=38.2$  to  $11.1$ . The  
20   optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table. The lens surface added with \* are aspheric surfaces.

**Table13** Optical characteristics

Sur-face	R	D	N d	$\nu$ d	Note
1	34. 733	1. 000	1. 84666	23. 8	First lens
2	23. 249	2. 992	1. 49700	81. 6	Second lens
3	50. 425	0. 100			
4*	19. 468	3. 048	1. 72916	54. 7	Third lens
5	67. 451	d 1			
6*	86. 341	0. 800	1. 80518	25. 5	Fourth lens
7	5. 603	4. 512			
8	-9. 394	0. 800	1. 49700	81. 6	Fifth lens
9	13. 186	2. 087	1. 84666	23. 8	Sixth lens
10	-33. 540	d 2			
11	0. 000	0. 100			
12	9. 855	1. 418	1. 74077	27. 8	Seventh lens
13	615. 630	1. 279			
14	8. 944	1. 382	1. 84666	23. 8	Eighth lens
15	4. 082	2. 977	1. 64000	60. 2	Ninth lens
16	-6. 047	2. 648	1. 80610	33. 3	Tenth lens
17	8. 079	1. 883			
18*	8. 267	2. 364	1. 48749	70. 4	Eleventh lens
19	-13. 748	d 3			
20	0. 000	1. 980	1. 51680	64. 2	Filter, cover glass
21	0. 000				

The optical surfaces on the fourth, the sixth, and the eighteenth surfaces in Table 13 are aspheric surfaces, and parameters relating to expression (25) on the respective aspheric surfaces are as shown in the

following table.

**Table14** Coefficient of aspheric surface

	K	$A_4$	$A_6$	$A_8$	$A_{10}$
4	-0.06563	-2.49787E-06	1.31109E-08	-2.07098E-10	7.80637E-13
6	117.23187	1.94059E-04	-3.89470E-06	6.63457E-08	-6.24076E-10
18	-2.7548	1.24489E-05	1.01915E-05	-8.16729E-07	2.67482E-08

The interval d1 between the first group optical system G1 and the second group optical system G2, the interval d2 between the second group optical system G2 and the diaphragm FA, and the interval d3 between the third group optical system G3 and the optical filter OF are variable, and these variable intervals d1, d2, and d3 are changed as shown in the following table, corresponding to the focal length f of the whole system, accompanying zooming.

**Table15** Variable intervals

	f	d 1	d 2	d 3
Wide	5.899	1.000	14.870	4.812
Mean	11.108	5.956	6.058	7.771
Tele	23.611	14.670	0.882	9.585

10

The parameter values according to the respective conditional expressions (1) to (3) of the present invention in example 1-4 are as shown in the following table, and within the range of the respective

conditional expressions.

**Table 16** Parameter values in conditional expressions

$N_p - N_n$	-0.186
$v_p - v_n$	31.68
$K_{12} / (f_w + f_t)$	0.804

The aberration diagram in example 1-4 is illustrated in Fig. 11.

Fig. 5 is a schematic diagram of an optical system of example 1-5 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a diaphragm FA, and an optical filter (including a cover glass) OF. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the sixth lenses E4 to E6 constitute the second group optical system G2, and the seventh to the eleventh lenses E7 to E11 constitute the third group optical system G3.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. The diaphragm FA is arranged on the object side of the third group optical system G3, and operates integrally with the third group optical system G3. Surface numbers of the respective optical surfaces are added for

reference. The respective reference signs in Fig. 5 are used independently for each example, in order to avoid complexity due to an increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common  
5 configuration to other examples.

In Fig. 5, for example, the first lens E1, the second lens E2, the third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the diaphragm FA, the seventh lens E7, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, and the optical filter OF  
10 are arranged in order from the object side of a subject or the like, and an image is formed at the back of the optical filter OF having various optical filtering functions.

The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus  
15 lens formed in a convex shape on the object side, and the third lens E3 is a positive meniscus lens formed in a convex shape on the object side. The first lens E1 and the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

20 The fourth lens E4 is a negative meniscus lens formed in a convex shape on the object side, the fifth lens E5 is a negative lens including a double-concave lens, and the sixth lens E6 is a positive meniscus lens formed in a convex shape on the object side. The fifth lens E5 and the sixth lens E6 form a densely cemented doublet, and the  
25 second group optical system G2 formed of the fourth to the sixth lenses



E4 to E6 exhibits a negative focal length as a whole.

The seventh lens E7 is a positive lens including a double-convex lens, the eighth lens E8 is a negative meniscus lens formed in a convex shape on the object side, the ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a negative lens including a double-concave lens, and the eleventh lens E11 is a positive lens including a double-convex lens. The eighth to the tenth lenses E8 to E10 form a densely cemented triplet, and the third group optical system G3 formed of the seventh to the eleventh lenses E7 to E11 exhibits a positive focal length as a whole. The diaphragm FA arranged between the second group optical system G2 and the third group optical system G3 operates integrally with the third group optical system G3, and the distance from the third group optical system G3 is constant.

The optical filter OF arranged on the image surface side of the eleventh lens E11 in the third group optical system G3 may include a cover glass of a solid image capturing device 53 such as a CCD image capturing device, and has various optical filtering functions.

In this example 1-5, the fifth surface, being a surface on the object side of the third lens E3 located closest to the image surface side in the first group optical system G1, and the twelfth surface, being a surface on the object side of the seventh lens E7 located closest to the object side in the third group optical system G3, and the eighteenth surface, being a surface on the object side of the eleventh lens E11 located closest to the object side in the third group optical system G3, are respectively aspheric surfaces.

The shift of the respective group optical systems G1 to G3 accompanying zooming between the wide-angle end, that is, the short focal-length side, and the telephoto end, that is, the long focal-length side is, as illustrated in Fig. 5, such that the first group optical system

5 G1 shifts from the object side toward the image surface side with a shift from the short focal-length side to the intermediate focal length, and shifts from the image surface side toward the object side with a shift from the intermediate focal length to the long focal-length side, and the

10 second group optical system G2 shifts from the object side toward the image surface side with a shift from the short focal-length side to the long focal-length side, and the third group optical system G3 shifts from the image surface side toward the object side with a shift from the short focal-length side to the long focal-length side.

In example 1-5, the focal length  $f$  of the whole system, the  $F$

15 number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=5.900$  to  $23.601$ ,  $F=2.79$  to  $3.41$ , and  $\omega=38.2$  to  $11.1$ . The optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table. The lens surface added with \* are aspheric surfaces.

**Table 17** Optical characteristics

Sur-face	R	D	N d	$\nu$ d	Note
1	41.101	1.000	1.84666	23.8	First lens
2	27.440	3.306	1.49700	81.6	Second lens
3	100.995	0.100			
4	26.505	2.824	1.72916	54.7	Third lens
5*	70.464	d 1			
6	28.455	0.800	1.88300	40.8	Fourth lens
7	6.027	3.779			
8	-15.765	0.800	1.51680	64.2	Fifth lens
9	8.236	2.599	1.80610	33.3	Sixth lens
10	1529.601	d 2			
11	0.000	0.100			
12*	10.421	1.809	1.67790	55.5	Seventh lens
13	-29.776	1.516			
14	8.644	0.800	1.83500	43.0	Eighth lens
15	4.195	2.733	1.69680	55.5	Ninth lens
16	-7.222	2.126	1.80610	33.3	Tenth lens
17	6.041	3.461			
18*	8.570	2.475	1.49700	81.6	Eleventh lens
19	-22.851	d 3			
20	0.000	1.980	1.51680	64.2	Filter, cover glass
21	0.000				

The optical surfaces on the fifth, the twelfth and the eighteenth surfaces in Table 17 are aspheric surfaces, and parameters relating to expression (25) on the respective aspheric surfaces are as shown in the

following table.

**Table18** Coefficient of aspheric surface

	K	A <sub>4</sub>	A <sub>6</sub>	A <sub>8</sub>	A <sub>10</sub>
5	2.46107	-7.24240E-07	-9.03070E-09	4.96805E-11	-9.91944E-14
12	0.97492	-2.21645E-04	4.93689E-07	-3.04146E-07	1.17057E-08
18	-1.91564	4.52271E-05	2.48651E-06	4.43265E-08	-2.17094E-09

The interval d1 between the first group optical system G1 and the second group optical system G2, the interval d2 between the second group optical system G2 and the diaphragm FA, and the interval d3 between the third group optical system G3 and the optical filter OF are variable, and these variable intervals d1, d2, and d3 are changed as shown in the following table, corresponding to the focal length f of the whole system, accompanying zooming.

**Table19** Variable intervals

	f	d 1	d 2	d 3
Wide	5.900	1.000	15.853	1.835
Mean	12.301	1.870	2.751	7.225
Tele	23.601	19.269	1.002	6.494

10

The parameter values according to the respective conditional expressions (1) to (3) of the present invention in example 1-5 are as shown in the following table, and within the range of the respective

conditional expressions.

**Table20** Parameter values in conditional expressions

$N_p - N_n$	-0.124
$v_p - v_n$	17.34
$K12 / (f_w + f_t)$	1.004

The aberration diagram in example 1-5 is illustrated in Fig. 12.

Fig. 6 is a schematic diagram of an optical system of example 1-6 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a diaphragm FA, and an optical filter (including a cover glass) OF. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the sixth lenses E4 to E6 constitute the second group optical system G2, and the seventh to the eleventh lenses E7 to E11 constitute the third group optical system G3.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. The diaphragm FA is arranged on the object side of the third group optical system G3, and operates integrally with the third group optical system G3. Surface numbers of the respective optical surfaces are added for reference. The respective reference signs in Fig. 6 are used

independently for each example, in order to avoid complexity due to an increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

5           For example, the first lens E1, the second lens E2, the third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the diaphragm FA, the seventh lens E7, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, and the optical filter OF are arranged in order from the object side of a subject or the like, and  
10   an image is formed at the back of the optical filter OF having various optical filtering functions.

          The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3  
15   is a positive meniscus lens formed in a convex shape on the object side. The first lens E1 and the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

          The fourth lens E4 is a negative meniscus lens formed in a  
20   convex shape on the object side, the fifth lens E5 is a negative lens including a double-concave lens, and the sixth lens E6 is a positive meniscus lens formed in a convex shape on the object side. The fifth lens E5 and the sixth lens E6 form a densely cemented doublet, and the second group optical system G2 formed of the fourth to the sixth lenses  
25   E4 to E6 exhibits a negative focal length as a whole.

The seventh lens E7 is a positive lens including a double-convex lens, the eighth lens E8 is a negative lens including a double-concave, the ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a negative lens including a double-concave lens, and  
5 the eleventh lens E11 is a positive meniscus lens formed in a convex shape on the object side. The eighth lens E8 to the tenth lens E10 form a densely cemented triplet, and the third group optical system G3 formed of the seventh to the eleventh lenses E7 to E11 exhibits a positive focal length as a whole. The diaphragm FA arranged between  
10 the second group optical system G2 and the third group optical system G3 operates integrally with the third group optical system G3, and the distance from the third group optical system G3 is constant.

The optical filter OF arranged on the image surface side of the eleventh lens E11 in the third group optical system G3 may include a  
15 cover glass of a solid image capturing device 53 such as a CCD image capturing device, and has various optical filtering functions.

In this example 1-6, the sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second group optical system G2, the twelfth surface, being a surface on  
20 the object side of the seventh lens E7 located closest to the object side in the third group optical system G3, and the seventeenth surface, being a surface of the tenth lens E10 located closest to the image surface side of the cemented triplet lens in the third group optical system G3, are respectively aspheric surfaces.

25 The shift of the respective group optical systems G1 to G3

accompanying zooming between the wide-angle end, that is, the short focal-length side, and the telephoto end, that is, the long focal-length side is, as illustrated in Fig. 6, such that the first group optical system G1 shifts from the image surface side toward the object side with a shift  
5 from the short focal-length side to the long focal-length side, and the second group optical system G2 shifts from the object side toward the image surface side, and the third group optical system G3 shifts from the image surface side toward the object side.

In example 1-6, the focal length  $f$  of the whole system, the F  
10 number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=5.900$  to  $35.404$ ,  $F=3.60$  to  $3.88$ , and  $\omega=38.2$  to  $7.5$ . The optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table. The lens surface added with \* are aspheric surfaces.



**Table 21** Optical characteristics

Sur-face	R	D	N d	$\nu$ d	Note
1	38.793	1.000	1.84666	23.8	First lens
2	22.685	4.517	1.49700	81.6	Second lens
3	124.293	0.100			
4	22.311	2.647	1.88300	40.8	Third lens
5	49.396	d 1			
6*	35.371	0.800	1.75520	27.5	Fourth lens
7	5.412	4.129			
8	-13.289	0.800	1.58913	61.3	Fifth lens
9	7.995	2.469	1.84666	23.8	Sixth lens
10	421.332	d 2			
11	0.000	0.100			
12*	7.562	1.898	1.73400	51.1	Seventh lens
13	-38.284	2.067			
14	-35.087	0.800	1.83400	37.3	Eighth lens
15	7.872	2.492	1.74400	44.9	Ninth lens
16	-4.880	1.587	1.80518	25.5	Tenth lens
17*	551.001	5.986			
18	9.387	1.699	1.51742	52.2	Eleventh lens
19	21.436	d 3			
20	0.000	1.980	1.51680	64.2	Filter, cover glass
21	0.000				

The optical surfaces on the sixth, the twelfth, and the seventeenth surfaces in Table 21 are aspheric surfaces, and parameters relating to expression (25) on the respective aspheric

surfaces are as shown in the following table.

**Table22** Coefficient of aspheric surface

	K	$A_4$	$A_6$	$A_8$	$A_{10}$
6	-15.51346	1.19918E-04	-1.08642E-06	1.01994E-08	-4.97906E-11
12	0.54508	-2.93810E-04	-5.76520E-06	8.86556E-08	-1.12299E-08
17	-2185.272	6.31874E-04	1.34142E-05	4.20069E-07	3.70498E-09

The interval d1 between the first group optical system G1 and the second group optical system G2, the interval d2 between the second group optical system G2 and the diaphragm FA, and the interval d3 between the third group optical system G3 and the optical filter OF are variable, and these variable intervals d1, d2, and d3 are changed as shown in the following table, corresponding to the focal length f of the whole system, accompanying zooming.

**Table23** Variable intervals

	f	d 1	d 2	d 3
Wide	5.900	1.000	16.155	1.928
Mean	13.702	8.393	6.412	6.451
Tele	35.404	18.941	1.011	8.975

10

The parameter values according to the respective conditional expressions (1) to (3) of the present invention in example 1-6 are as shown in the following table, and within the range of the respective conditional expressions.

**Table24** Parameter values in conditional expressions

$N_p - N_n$	-0.076
$v_p - v_n$	13.50
$K_{12} / (f_w + f_t)$	0.915

The aberration diagram in example 1-6 is illustrated in Fig. 13.

Fig. 7 is a schematic diagram of an optical system of example 1-7 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a diaphragm FA, and an optical filter (including a cover glass) OF. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the sixth lenses E4 to E6 constitute the second group optical system G2, and the seventh to the eleventh lenses E7 to E11 constitute the third group optical system G3.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. The diaphragm FA is arranged on the object side of the third group optical system G3, and operates integrally with the third group optical system G3. Surface numbers of the respective optical surfaces are added for reference. The respective reference signs in Fig. 7 are used independently for each example, in order to avoid complexity due to an

increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

For example, the first lens E1, the second lens E2, the third lens  
5 E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the diaphragm FA, the seventh lens E7, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, and the optical filter OF are arranged in order from the object side of a subject or the like, and an image is formed at the back of the optical filter OF having various  
10 optical filtering functions.

The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3 is a positive meniscus lens formed in a convex shape on the object side.  
15 The first lens E1 and the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

The fourth lens E4 is a negative meniscus lens formed in a convex shape on the object side, the fifth lens E5 is a negative lens  
20 including a double-concave lens, and the sixth lens E6 is a positive meniscus lens formed in a convex shape on the object side. The fifth lens E5 and the sixth lens E6 is a positive lens including double-convex lens, and the second group optical system G2 formed of the fourth to the sixth lenses E4 to E6 exhibits a negative focal length as a whole.

25 The seventh lens E7 is a positive lens including a double-convex

lens, the eighth lens E8 is a negative meniscus lens formed in a convex shape on the object side, the ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a negative lens including a double-concave lens, and the eleventh lens E11 is a positive lens including a double-convex lens.

The eighth lens E8 to the tenth lens E10 form a densely cemented triplet, and the third group optical system G3 formed of the seventh to the eleventh lenses E7 to E11 exhibits a positive focal length as a whole. The diaphragm FA arranged between the second group optical system G2 and the third group optical system G3 operates integrally with the third group optical system G3, and the distance from the third group optical system G3 is constant.

The optical filter OF arranged on the image surface side of the eleventh lens E11 in the third group optical system G3 may include a cover glass of a solid image capturing device 53 such as a CCD image capturing device, and has various optical filtering functions. In this example 1-7, the sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second group optical system G2, the twelfth surface, being a surface on the object side of the seventh lens E7 located closest to the object side in the third group optical system G3, and the eighteenth surface, being a surface of the object side of the eleventh lens E11 located closest to the object side of the third group optical system G3, are respectively aspheric surfaces.

The shift of the respective group optical systems G1 to G3

accompanying zooming between the wide-angle end, that is, the short focal-length side, and the telephoto end, that is, the long focal-length side is, as illustrated in Fig. 7, such that the first group optical system G1 shifts from the image surface side toward the object side with a shift  
5 from the short focal-length side to the long focal-length side, and the second group optical system G2 shifts from the object side toward the image surface side, and the third group optical system G3 shifts from the image surface side toward the object side.

In example 1-7, the focal length  $f$  of the whole system, the F  
10 number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=5.898$  to  $23.605$ ,  $F=2.79$  to  $3.45$ , and  $\omega=38.3$  to  $11.1$ . The optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table. The lens surface added with \* are aspheric surfaces.

**Table25** Optical characteristics

Sur-face	R	D	N d	$\nu$ d	Note
1	43.992	1.000	1.84666	23.8	First lens
2	24.879	3.499	1.56384	60.8	Second lens
3	125.477	0.100			
4	22.003	2.758	1.78800	47.5	Third lens
5	49.308	d 1			
6*	52.156	0.800	1.78472	25.7	Fourth lens
7	5.356	4.310			
8	-9.221	0.800	1.49700	81.6	Fifth lens
9	11.763	1.532	1.84666	23.8	Sixth lens
10	-44.183	d 2			
11	0.000	0.245			
12*	8.247	2.509	1.60342	38.0	Seventh lens
13	-25.143	2.064			
14	15.998	0.800	1.83400	37.3	Eighth lens
15	4.105	2.812	1.72000	50.3	Ninth lens
16	-5.274	0.816	1.80518	25.5	Tenth lens
17	7.832	1.209			
18*	9.914	3.565	1.59551	39.2	Eleventh lens
19	-15.402	d 3			
20	0.000	1.980	1.51680	64.2	Filter, cover glass
21	0.000				

The optical surfaces on the sixth, the twelfth, and the eighteenth surfaces in Table 25 are aspheric surfaces, and parameters relating to

expression (25) on the respective aspheric surfaces are as shown in the following table.

**Table26** Coefficient of aspheric surface

	K	$A_4$	$A_6$	$A_8$	$A_{10}$
6	47.18823	1.66302E-04	-4.75304E-06	9.68797E-08	-1.16785E-09
12	0.40944	-3.51364E-04	-3.22505E-06	1.56822E-07	-1.19092E-08
18	-2.14701	4.57066E-05	8.65923E-06	-6.34640E-07	2.42648E-08

The interval d1 between the first group optical system G1 and the second group optical system G2, the interval d2 between the second group optical system G2 and the diaphragm FA, and the interval d3 between the third group optical system G3 and the optical filter OF are variable, and these variable intervals d1, d2, and d3 are changed as shown in the following table, corresponding to the focal length f of the whole system, accompanying zooming.

**Table27** Variable intervals

	f	d 1	d 2	d 3
Wide	5.898	1.084	12.884	5.226
Mean	11.177	5.946	4.759	8.702
Tele	23.605	16.881	0.910	10.244

The parameter values according to the respective conditional expressions (1) to (3) of the present invention in example 1-7 are as



shown in the following table, and within the range of the respective conditional expressions.

**Table 28** Parameter values in conditional expressions

$N_p - N_n$	-0.100
$v_p - v_n$	18.94
$K_{12} / (f_w + f_t)$	0.925

The aberration diagram in example 1-7 is illustrated in Fig. 14.

5            Example 1-6 covers a case when the aperture diaphragm at the long focal-length side is made large with respect to that at the short focal-length side, to decrease the F number at the long focal-length side.

10           In the respective lenses, a diaphragm for shading a part of beams of a mean angle of view can be arranged between the second group optical system G2 and the third group optical system G3, in the zooming range other than the long focal-length side. Therefore, an example of the aberration diagram when the diaphragm for shading is provided in the seventh embodiment is illustrated in Fig. 15. The position of the diaphragm for shading in this case is as follows.

Short focal-length side:            At a position of 10 millimeters from the second group optical system G2 toward the image surface side.

Mean focal-length:            At a position of 1 millimeter from the second group optical system G2 toward the image surface side.

In this example, an example, in which the position of the diaphragm for shading and the diameter of the diaphragm are changed in order to shade a part of the beams of the mean image height from the short focal-length side to the mean focal length, is shown, but the  
5 position and the diameter may be fixed corresponding to the aberration situation, and for example, the zooming range to be shaded may be only at the short focal-length side.

As is obvious from example 1-1 to example 1-7, since the zoom lens according to the first embodiment has the number of lenses as  
10 small as 10 to 11, and is very compact, it can correspond to resources saving. Further, various aberrations from the chromatic aberration down can be favorably corrected over the whole zoom range, so as to be able to correspond to image capturing devices of 3,000,000 pixels or more, while the half angle of view on the short focal length side is as  
15 wide as equal to or more than 38 degrees, and the magnification is as high as 3X to 6X. Further, since an optical glass that is chemically stable and does not contain any toxic substance such as lead or arsenic is used, the materials can be recycled, and hence conservation of global environment is possible, without having water pollution due to  
20 waste fluid at the time of machining. Further, by using the zoom lens according to the respective examples as a shooting lens in a camera, considerable miniaturization, light weight, and low cost can be realized, and electric power saving can be achieved, while maintaining high performance as a camera. By constituting a mobile information  
25 terminal by adding a communication function to such a camera function,

considerable miniaturization, light weight, and low cost of the mobile information terminal can be realized, and electric power saving can be achieved.

Specific configuration and numerical examples are shown in example 2, as an example of the zoom lens according to the fourth embodiment of the present invention. In each example, the aberrations of the zoom lens are sufficiently corrected, and correspondence to the photodetector with 3,000,000 to 5,000,000 pixels becomes possible. It will be obvious from the examples below, that excellent imaging performance can be ensured, while achieving sufficient miniaturization and wide angle of view, by forming the zoom lens as shown in the fourth embodiment.

In example 2, various signs as described below are used.

$f$ : Focal length of the whole system

15  $F$ : F number

$\omega$ : Half angle of view

$R$ : Radius of curvature

$D$ : Spacing

$N_d$ : Refractive index

20  $v_d$ : Abbe constant

$K$ : Conical constant of the aspheric surface

$A_4$ : Fourth coefficient of the aspheric surface

$A_6$ : Sixth coefficient of the aspheric surface

$A_8$ : Eighth coefficient of the aspheric surface

25  $A_{10}$ : Tenth coefficient of the aspheric surface

However, the aspheric surface used herein is defined by the following expression, when it is assumed that a reciprocal of a paraxial radius of curvature (paraxial curvature) is C, and the height from the optical axis is H.

$$5 \quad X = \frac{CH^2}{1 + \sqrt{(1 - (1 + K)C^2H^2)}} + A_4 \cdot Y^4 + A_6 \cdot Y^6 + A_8 \cdot Y^8 + A_{10} \cdot Y^{10} \quad (26)$$

Fig. 19 is a schematic diagram of an optical system of example 2-1 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, 10 a ninth lens E9, a tenth lens E10, an eleventh lens E11, a twelfth lens E12 a diaphragm FA, and an optical filter (including a cover glass) OF. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the sixth lenses E4 to E6 constitute the second group optical system G2, the seventh to the 15 eleventh lenses E7 to E11 constitute the third group optical system G3, and the twelfth lens E12 constitutes the fourth group optical system G4.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. Surface 20 numbers of the respective optical surfaces are added for reference. The respective reference signs in Fig. 19 are used independently for each example, in order to avoid complexity due to an increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common

configuration to other examples.

For example, the first lens E1, the second lens E2, the third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the diaphragm FA, the seventh lens E7, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, the twelfth lens E12, and the optical filter OF are arranged in order from the object side of a subject or the like, and an image is formed at the back of the optical filter OF having various optical filtering functions.

The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3 is a positive meniscus lens formed in a convex shape on the object side. The first lens E1 and the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

The fourth lens E4 is a negative lens including double-convex lens, the fifth lens E5 is also a negative lens including a double-concave lens, and the sixth lens E6 is a positive lens including a double-convex lens. The fifth lens E5 and the sixth lens E6 are densely cemented doublet, and the second group optical system formed of the fourth to the sixth lenses E4 to E6 exhibits a negative focal length as a whole.

The seventh lens E7 is a positive lens including a double-convex lens, the eighth lens E8 is a negative meniscus lens formed in a convex shape on the object side, the ninth lens E9 is a positive lens including a

double-convex lens, the tenth lens E10 is a negative lens including a double-concave lens, and the eleventh lens E11 is a positive lens including a double-convex lens.

5 The eighth lens E8 to the tenth lens E10 form a densely cemented triplet, and the third group optical system G3 formed of the seventh to the eleventh lenses E7 to E11 exhibits a positive focal length as a whole. The twelfth lens E12 is a positive meniscus lens formed in a convex shape on the object side. The twelfth lens E12 alone constitutes the fourth group optical system G4 that has a positive focal  
10 length.

The diaphragm FA is arranged between the second group optical system G2 and the third group optical system G3, and the distance from the diaphragm FA to the second group optical system G2 and to the third group optical system G3 are respectively variable.

15 The optical filter OF arranged on the image surface side of the twelfth lens E12 in the fourth group optical system G4 is integrally supported with the fourth group optical system G4, and has various optical filtering functions.

In this example 2-1, the sixth surface, being a surface on the  
20 object side of the fourth lens E4 located closest to the object side in the second group optical system G2, the twelfth surface, being a surface on the object side of the seventh lens E7 located closest to the object side in the third group optical system G3, and the twentieth surface, being a surface of the object side of the twelfth lens E12 located closest to the  
25 object side of the fourth group optical system G4, are respectively

aspheric surfaces.

Accompanying zooming between the wide-angle end, that is, the short focal-length side, and the telephoto end, that is, the long focal-length side, the second group optical system G2 shifts from the image surface side toward the object side, the third group optical system G3 that mainly takes on a zooming function and an image-surface compensating function shifts from the image surface side toward the object side.

In example 2-1, the focal length  $f$  of the whole system, the F number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=5.8$  to  $17.3$ ,  $F=2.71$  to  $3.88$ , and  $\omega=40.98$  to  $14.65$ . The optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table.

**Table29** Optical characteristics

Surface number	R	D	N d	$\nu$ d
1	120. 000	1. 40	1. 84666	23. 78
2	47. 947	4. 00	1. 77250	49. 62
3	777. 800	0. 10		
4	34. 000	3. 13	1. 62299	58. 12
5	174. 440	(Variable)		
6 (Aspheric surface)	-86. 538	1. 00	1. 69700	48. 51
7	7. 654	5. 00		
8	-12. 100	3. 50	1. 51742	52. 15
9	19. 645	3. 22	1. 74950	35. 04
10	-23. 799	(Variable)		
11 (Diaphragm)	$\infty$	(Variable)		
12 (Aspheric surface)	11. 864	3. 10	1. 74400	44. 72
13	-214. 330	1. 25		
14	16. 470	0. 80	1. 75520	27. 53
15	7. 800	4. 50	1. 51680	64. 20
16	-124. 000	0. 80	1. 75520	27. 53
17	8. 710	0. 61		
18	17. 585	2. 25	1. 62041	60. 34
19	-34. 112	(Variable)		
20 (Aspheric surface)	10. 920	2. 53	1. 48749	70. 44
21	100. 000	3. 16		
22	$\infty$	3. 26	1. 51680	64. 20
23	$\infty$			



The respective optical surfaces on the sixth surface, the twelfth surface, and the twentieth surface, described as "aspheric surface" in Table 29, are respectively aspheric surfaces, and parameters relating to the expression (26) on each aspheric surface are as follows.

5           Aspheric surface: the sixth surface

$$K=0$$

$$A_4=1.12052 \times 10^{-4}$$

$$A_6=-8.10477 \times 10^{-7}$$

$$A_8=4.62470 \times 10^{-5}$$

10            $A_{10}=-1.54132 \times 10^{-11}$

Aspheric surface: the twelfth surface

$$K=0$$

$$A_4=-7.35995 \times 10^{-5}$$

$$A_6=7.34774 \times 10^{-8}$$

15            $A_8=-6.373950 \times 10^{-9}$

$$A_{10}=-1.28077 \times 10^{-12}$$

Aspheric surface: the twentieth surface

$$K=0$$

$$A_4=-6.86256 \times 10^{-5}$$

20            $A_6=2.33037 \times 10^{-6}$

$$A_8=-9.02050 \times 10^{-8}$$

$$A_{10}=1.62904 \times 10^{-9}$$

The interval  $D_5$  between the first group optical system G1 and the second group optical system G2, the interval  $D_{10}$  between the  
25   second group optical system G2 and the diaphragm FA, the interval  $D_{11}$

between the diaphragm FA and the third group optical system G3, and the interval  $D_{19}$  between the third group optical system G3 and the fourth group optical system G4 are variable, and these variable intervals  $D_5$ ,  $D_{10}$ ,  $D_{11}$ , and  $D_{19}$  are changed as shown in the following table, accompanying zooming.

**Table30** Variable interval

	Wide-angle end	Mean focal length	Telephoto end
$f$	5.80	11.60	17.30
$D_5$	1.20	11.32	15.14
$D_{10}$	14.95	4.83	1.01
$D_{11}$	7.24	3.95	1.00
$D_{19}$	2.00	5.30	8.25

The numerical values according to the respective conditional expressions of the present invention in example 2-1 are as shown in the following table, and within the range of the respective conditional expressions or values close to the range.

Numerical values in the conditional expressions

$$N_{c2} (N_{15-16})=1.51680$$

$$v_{c2} (v_{15-16})=64.20$$

$$N_{c1} (N_{14-15})=1.75520$$

$$v_{c1} (v_{14-15})=27.53$$

$$N_{c3} (N_{16-17})=1.75520$$

$$v_{c3} (v_{16-17})=27.53$$

$$R_{c2}/R_{c4}(R_{15}/R_{17})=0.896 (=7.800/8.710)$$

Fig. 20 is a schematic diagram of an optical system of example 2-2 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a twelfth lens E12, a diaphragm FA, and an optical filter (including a cover glass) OF. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the sixth lenses E4 to E6 constitute the second group optical system G2, and the seventh to the eleventh lenses E7 to E11 constitute the third group optical system G3, and the twelfth lens E12 constitutes the fourth group optical system G4.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. The respective reference signs in Fig. 20 are used independently for each example, in order to avoid complexity due to an increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

In Fig. 20, for example, the first lens E1, the second lens E2, the third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the diaphragm FA, the seventh lens E7, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, the twelfth lens E12, and

the optical filter OF are arranged in order from the object side of a subject or the like, and an image is formed at the back of the optical filter OF having various optical filtering functions.

The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3 is a positive meniscus lens formed in a convex shape on the object side. The first lens E1 and the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

The fourth lens E4 is a negative lens including a double-concave lens, the fifth lens E5 is also a negative lens including a double-concave lens, and the sixth lens E6 is a positive lens including a double-convex lens. The fifth lens E5 and the sixth lens E6 form a densely cemented doublet, and the second group optical system G2 formed of the fourth to the sixth lenses E4 to E6 exhibits a negative focal length as a whole. The seventh lens E7 is a positive lens including a double-convex lens, the eighth lens E8 is a negative meniscus lens formed in a convex shape on the object side, the ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a negative lens including a double-concave lens, and the eleventh lens E11 is a positive lens including a double-convex lens. The eighth to the tenth lenses E8 to E10 form a densely cemented triplet, and the third group optical system G3 formed of the seventh to the eleventh lenses E7 to E11 exhibits a positive focal length as a

whole. The twelfth lens E12 is a positive meniscus lens formed in a convex shape on the object side, and the twelfth lens E12 alone constitutes the fourth group optical system G4 and the third group optical system G3. The diaphragm FA is arranged between the second group optical system G2 and the third group optical system G3, and the distances from the diaphragm FA to the optical system G2 and the optical system G3 are respectively variable.

The optical filter OF arranged on the image surface side of the twelfth lens E12 in the fourth group optical system G4 is integrally supported with the fourth group optical system G4 and has various optical filtering functions.

In this example 2-2, the sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second group optical system G2, the twelfth surface, being a surface on the object side of the seventh lens E7 located closest to the object side in the third group optical system G3, and the twentieth surface, being a surface on the object side of the twelfth lens E12 that constitutes the fourth group optical system G4 are respectively aspheric surfaces.

Accompanying zooming between the wide-angle end, that is, the short focal-length side, and the telephoto end, that is, the long focal-length side, the second group optical system G2 shifts from the object side toward the image surface side, and the third group optical system G3 that mainly takes on a zooming function and an image-surface compensating function shifts from the image surface side toward the object side.

In example 2-2, the focal length  $f$  of the whole system, the F number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=5.8$  to  $23.2$ ,  $F=2.77$  to  $4.17$ , and  $\omega=40.08$  to  $11.02$ . The optical characteristics relating to the respective optical surfaces and the

5 optical elements are as shown in the following table.

**Table31** Optical characteristics

Surface number	R	D	N d	$\nu$ d
1	120.000	1.40	1.84666	23.78
2	47.947	4.00	1.77250	49.62
3	777.812	0.10		
4	34.000	3.26	1.62041	60.34
5	174.440	(Variable)	1.00000	
6 (Aspheric surface)	-189.660	1.00	1.80610	40.73
7	8.326	5.48		
8	-12.745	1.00	1.48749	70.44
9	16.747	3.56	1.74950	35.04
10	-25.024	(Variable)		
11 (Diaphragm)	$\infty$	(Variable)		
12 (Aspheric surface)	10.726	3.43	1.74400	44.90
13	-64.740	0.46		
14	22.316	0.80	1.69895	30.05
15	7.800	4.50	1.48749	70.44
16	-99.262	0.80	1.75520	27.53
17	8.337	0.68		
18	18.012	2.30	1.62041	60.34
19	-28.240	(Variable)		
20 (Aspheric surface)	10.975	2.20	1.48749	70.44
21	30.000	3.16		
22	$\infty$	3.26	1.51680	64.20
23	$\infty$			

The respective optical surfaces on the sixth surface, the twelfth surface, and the twentieth surface, described as "aspheric surface" in Table 31, are respectively aspheric surfaces, and parameters relating to the expression (26) on each aspheric surface are as follows.

5 Aspheric surface: the sixth surface

$$K=0$$

$$A_4=7.57026 \times 10^{-5}$$

$$A_6=-5.91870 \times 10^{-7}$$

$$A_8=4.32704 \times 10^{-9}$$

10  $A_{10}=-1.78040 \times 10^{-11}$

Aspheric surface: the twelfth surface

$$K=0$$

$$A_4=-1.14646 \times 10^{-4}$$

$$A_6=-1.28319 \times 10^{-7}$$

15  $A_8=-9.13454 \times 10^{-9}$

$$A_{10}=5.08427 \times 10^{-11}$$

Aspheric surface: the twentieth surface

$$K=0$$

$$A_4=-6.38620 \times 10^{-5}$$

20  $A_6=3.96426 \times 10^{-6}$

$$A_8=-1.65462 \times 10^{-7}$$

$$A_{10}=3.08386 \times 10^{-9}$$

The interval  $D_5$  between the first group optical system G1 and the second group optical system G2, the interval  $D_{10}$  between the  
25 second group optical system G2 and the diaphragm FA, the interval  $D_{11}$



between the diaphragm FA and the third group optical system G3, and the interval  $D_{19}$  between the third group optical system G3 and the fourth group optical system G4 are variable, and these variable intervals  $D_5$ ,  $D_{10}$ ,  $D_{11}$ , and  $D_{19}$  are changed as shown in the following table, accompanying zooming.

**Table 32** Variable interval

	Wide-angle end	Mean focal length	Telephoto end
$f$	5.80	14.50	23.20
$D_5$	1.20	14.43	18.70
$D_{10}$	18.50	5.27	1.00
$D_{11}$	7.91	4.12	1.00
$D_{19}$	2.00	5.80	8.92

The numerical values according to the respective conditional expressions of the present invention in example 2-2 are as shown in the following table, and within the range of the respective conditional expressions or values close to the range.

$$N_{c2} (N_{15-16}) = 1.48749$$

$$v_{c2} (v_{15-16}) = 70.44$$

$$N_{c1} (N_{14-15}) = 1.69895$$

$$v_{c1} (v_{14-15}) = 30.05$$

$$N_{c3} (N_{16-17}) = 1.75520$$

$$v_{c3} (v_{16-17}) = 27.53$$

$$R_{c2}/R_{c4}(R_{15}/R_{17})=0.936 (=7.800/8.337)$$

Fig. 21 is a schematic diagram of an optical system of example 2-3 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a twelfth lens E12, a diaphragm FA, and an optical filter (including a cover glass) OF. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the sixth lenses E4 to E6 constitute the second group optical system G2, and the seventh to the eleventh lenses E7 to E11 constitute the third group optical system G3, and the twelfth lens E12 constitutes the fourth group optical system G4.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. The respective reference signs in Fig. 20 are used independently for each example, in order to avoid complexity due to an increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

In Fig. 21, for example, the first lens E1, the second lens E2, the third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the diaphragm FA, the seventh lens E7, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, the twelfth lens E12, and the optical filter OF are arranged in order from the object side of a

subject or the like, and an image is formed at the back of the optical filter OF having various optical filtering functions.

The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3 is a positive meniscus lens formed in a convex shape on the object side. The first lens E1 and the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

The fourth lens E4 is a negative meniscus lens formed in a convex shape on the object side, the fifth lens E5 is a negative lens including a double-concave lens, and the sixth lens E6 is a positive lens including a double-convex lens. The fifth lens E5 and the sixth lens E6 form a densely cemented doublet, and the second group optical system G2 formed of the fourth to the sixth lenses E4 to E6 exhibits a negative focal length as a whole. The seventh lens E7 is a positive meniscus lens formed in a convex shape on the object side, the eighth lens E8 is a negative meniscus lens formed in a convex shape on the object side, the ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a negative lens including a double-concave lens, and the eleventh lens E11 is a positive lens including a double-convex lens. The eighth to the tenth lenses E8 to E10 form a densely cemented triplet, and the third group optical system G3 formed of the seventh to the eleventh lenses E7 to E11 exhibits a positive focal length as a whole. The twelfth lens E12 is a positive

meniscus lens formed in a convex shape on the object side, and the twelfth lens E12 alone constitutes the fourth group optical system G4 and the third group optical system G3. The diaphragm FA is arranged between the second group optical system G2 and the third group optical system G3, and the distances from the diaphragm FA to the optical system G2 and the optical system G3 are respectively variable.

The optical filter OF arranged on the image surface side of the twelfth lens E12 in the fourth group optical system G4 is integrally supported with the fourth group optical system G4 and has various optical filtering functions.

In this example 2-2, the sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second group optical system G2, the twelfth surface, being a surface on the object side of the seventh lens E7 located closest to the object side in the third group optical system G3, and the twentieth surface, being a surface on the object side of the twelfth lens E12 that constitutes the fourth group optical system G4 are respectively aspheric surfaces.

Accompanying zooming between the wide-angle end, that is, the short focal-length side, and the telephoto end, that is, the long focal-length side, the second group optical system G2 shifts from the object side toward the image surface side, and the third group optical system G3 that mainly takes on a zooming function and an image-surface compensating function shifts from the image surface side toward the object side.

In example 2-3, the focal length  $f$  of the whole system, the  $F$

number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=4.95$  to  $14.85$ ,  $F=2.97$  to  $4.13$ , and  $\omega=44.45$  to  $17.07$ . The optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table.

**Table33** Optical characteristics

Surface number	R	D	N d	$\nu$ d
1	340.249	1.40	1.84666	23.78
2	84.506	4.00	1.77250	49.62
3	-2061.000	0.10		
4	32.281	5.67	1.60311	60.69
5	103.000	(Variable)		
6 (Aspheric surface)	62.385	1.00	1.74400	44.90
7	6.720	5.73		
8	-14.335	2.00	1.60311	60.69
9	10.105	5.07	1.74950	35.04
10	-39.048	(Variable)		
11 (Diaphragm)	$\infty$	(Variable)		
12 (Aspheric surface)	9.406	2.68	1.74400	44.90
13	34.332	0.36		
14	13.923	0.80	1.75520	27.53
15	7.230	5.00	1.48749	70.44
16	-9.214	0.80	1.67270	32.17
17	28.990	0.25		
18	20.970	2.20	1.60311	60.69
19 (Aspheric surface)	-25.000	(Variable)		
20 (Aspheric surface)	34.300	2.00	1.48749	70.44
21	44.910	3.16		
22	$\infty$	3.26	1.51680	64.20
23	$\infty$			

The respective optical surfaces on the sixth surface, the twelfth surface, the nineteenth surface, and the twentieth surface, described as "aspheric surface" in Table 33, are respectively aspheric surfaces, and parameters relating to the expression (26) on each aspheric surface are as follows.

Aspheric surface: the sixth surface

$$K=0$$

$$A_4=7.68143 \times 10^{-5}$$

$$A_6=-5.7879 \times 10^{-7}$$

$$10 \quad A_8=3.43461 \times 10^{-9}$$

$$A_{10}=-1.26775 \times 10^{-11}$$

Aspheric surface: the twelfth surface

$$K=0$$

$$A_4=-5.90244 \times 10^{-5}$$

$$15 \quad A_6=-2.26307 \times 10^{-8}$$

$$A_8A_8=3.99618 \times 10^{-8}$$

$$A_{10}=-1.41064 \times 10^{-9}$$

Aspheric surface: the nineteenth surface

$$K=0$$

$$20 \quad A_4=4.15890 \times 10^{-4}$$

$$A_6=6.31024 \times 10^{-6}$$

$$A_8=-1.6099 \times 10^{-7}$$

$$A_{10}=9.6189 \times 10^{-9}$$

Aspheric surface: the twentieth surface

$$25 \quad K=0$$

$$A_4 = -4.83239 \times 10^{-5}$$

$$A_6 = 4.24081 \times 10^{-6}$$

$$A_8 = -3.49807 \times 10^{-7}$$

$$A_{10} = 8.93436 \times 10^{-9}$$

- 5 The interval  $D_5$  between the first group optical system G1 and the second group optical system G2, the interval  $D_{10}$  between the second group optical system G2 and the diaphragm FA, the interval  $D_{11}$  between the diaphragm FA and the third group optical system G3, and the interval  $D_{19}$  between the third group optical system G3 and the
- 10 fourth group optical system G4 are variable, and these variable intervals  $D_5$ ,  $D_{10}$ ,  $D_{11}$ , and  $D_{19}$  are changed as shown in the following table, accompanying zooming.

**Table 34** Variable interval

	Wide-angle end	Mean focal length	Telephoto end
f	4.95	9.90	14.85
$D_5$	1.20	11.64	15.03
$D_{10}$	14.83	4.39	1.00
$D_{11}$	6.50	3.76	1.00
$D_{19}$	2.00	4.74	7.49

- The numerical values according to the respective conditional
- 15 expressions of the present invention in example 2-3 are as shown in the following table, and within the range of the respective conditional expressions or values close to the range.



Numerical values in the conditional expressions

$$N_{c2} (N_{15-16})=1.48749$$

$$v_{c2} (v_{15-16})=70.44$$

$$N_{c1} (N_{14-15})=1.75520$$

5  $v_{c1} (v_{14-15})=27.53$

$$N_{c3} (N_{16-17})=1.67270$$

$$v_{c3} (v_{16-17})=32.17$$

$$R_{c2}/R_{c4}(R_{15}/R_{17})=0.249 (=7.230/28.990)$$

Fig. 22 is a schematic diagram of an optical system of example 2-4 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a twelfth lens E12 a diaphragm FA, and an optical filter (including a cover glass) OF.

15 In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the sixth lenses E4 to E6 constitute the second group optical system G2, the seventh to the eleventh lenses E7 to E11 constitute the third group optical system G3, and the twelfth lens E12 constitutes the fourth group optical system G4.

20 The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. Surface numbers of the respective optical surfaces are added for reference. The respective reference signs in Fig. 22 are used independently for

25 each example, in order to avoid complexity due to an increase in

number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

In Fig. 22, for example, the first lens E1, the second lens E2, the  
5 third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the diaphragm FA, the seventh lens E7, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, the twelfth lens E12, and the optical filter OF are arranged in order from the object side of a subject or the like, and an image is formed at the back of the optical  
10 filter OF having various optical filtering functions.

The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3 is a positive meniscus lens formed in a convex shape on the object side.  
15 The first lens E1 and the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

The fourth lens E4 is a negative lens including double-concave lens, the fifth lens E5 is also a negative lens including a  
20 double-concave lens, and the sixth lens E6 is a positive lens including a double-convex lens. The fifth lens E5 and the sixth lens E6 are densely cemented doublet, and the second group optical system formed of the fourth to the sixth lenses E4 to E6 exhibits a negative focal length as a whole.

25 The seventh lens E7 is a positive meniscus lens formed in a

convex shape on the object side, the eighth lens E8 is a negative meniscus lens formed in a convex shape on the object side, the ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a negative lens including a double-concave lens, and the  
5 eleventh lens E11 is a positive lens including a double-convex lens.

The eighth lens E8 to the tenth lens E10 form a densely cemented triplet, and the third group optical system G3 formed of the seventh to the eleventh lenses E7 to E11 exhibits a positive focal length as a whole. The twelfth lens E12 is a positive meniscus lens formed in  
10 a convex shape on the object side. The twelfth lens E12 alone constitutes the fourth group optical system G4 that has a positive focal length.

The diaphragm FA is arranged between the second group optical system G2 and the third group optical system G3, and the  
15 distance from the diaphragm FA to the second group optical system G2 and to the third group optical system G3 are respectively variable.

The optical filter OF arranged on the image surface side of the twelfth lens E12 in the fourth group optical system G4 is integrally supported with the fourth group optical system G4, and has various  
20 optical filtering functions.

In this example 2-4, the sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second group optical system G2, the twelfth surface, being a surface on the object side of the seventh lens E7 located closest to the object side  
25 in the third group optical system G3, and the twentieth surface, being a

surface of the object side of the twelfth lens E12 located closest to the object side of the fourth group optical system G4, are respectively aspheric surfaces.

Accompanying zooming between the wide-angle end, that is, the short focal-length side, and the telephoto end, that is, the long focal-length side, the second group optical system G2 shifts from the image surface side toward the object side, the third group optical system G3 that mainly takes on a zooming function and an image-surface compensating function shifts from the image surface side toward the object side.

In example 2-4, the focal length  $f$  of the whole system, the F number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=5.80$  to  $29.00$ ,  $F=3.01$  to  $4.58$ , and  $\omega=40.16$  to  $8.91$ . The optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table.

**Table35** Optical characteristics

Surface number	R	D	N d	$\nu$ d
1	120. 000	1. 40	1. 84666	23. 78
2	47. 947	4. 00	1. 77250	49. 62
3	777. 812	0. 10		
4	28. 848	3. 43	1. 62041	60. 34
5	76. 889	(Variable)		
6 (Aspheric surface)	-482. 650	1. 00	1. 72342	37. 99
7	8. 112	5. 70		
8	-14. 212	1. 32	1. 51680	64. 20
9	17. 367	3. 37	1. 75520	27. 53
10	-37. 226	(Variable)		
11 (Diaphragm)	$\infty$	(Variable)		
12 (Aspheric surface)	11. 729	3. 15	1. 74400	44. 90
13	1830. 000	0. 15		
14	23. 741	0. 80	1. 74950	35. 04
15	10. 996	6. 00	1. 48749	70. 44
16	-11. 275	0. 80	1. 69895	30. 05
17	11. 275	0. 78		
18	9. 792	4. 50	1. 60311	60. 69
19 (Aspheric surface)	-41. 240	(Variable)		
20 (Aspheric surface)	24. 847	2. 00	1. 75520	27. 53
21	30. 000	3. 16		
22	$\infty$	3. 26	1. 51680	64. 20
23	$\infty$			

The respective optical surfaces on the sixth surface, the twelfth surface, the nineteenth surface, and the twentieth surface, described as "aspheric surface" in Table 35, are respectively aspheric surfaces, and parameters relating to the expression (26) on each aspheric surface are as follows.

Aspheric surface: the sixth surface

$$K=0$$

$$A_4=8.12716 \times 10^{-5}$$

$$A_6=-4.73737 \times 10^{-7}$$

$$10 \quad A_8=2.32995 \times 10^{-9}$$

$$A_{10}=-6.6229 \times 10^{-12}$$

Aspheric surface: the twelfth surface

$$K=0$$

$$A_4=-4.04940 \times 10^{-5}$$

$$15 \quad A_6=1.08387 \times 10^{-7}$$

$$A_8=2.10711 \times 10^{-9}$$

$$A_{10}=-9.71445 \times 10^{-11}$$

Aspheric surface: the nineteenth surface

$$K=0$$

$$20 \quad A_4=2.66425 \times 10^{-4}$$

$$A_6=2.83525 \times 10^{-6}$$

$$A_8=6.42161 \times 10^{-9}$$

$$A_{10}=1.40725 \times 10^{-10}$$

Aspheric surface: the twentieth surface

$$25 \quad K=0$$

$$A_4 = -5.64236 \times 10^{-5}$$

$$A_6 = -2.46282 \times 10^{-7}$$

$$A_8 = -1.02479 \times 10^{-8}$$

$$A_{10} = -1.58903 \times 10^{-10}$$

- 5            The interval  $D_5$  between the first group optical system G1 and the second group optical system G2, the interval  $D_{10}$  between the second group optical system G2 and the diaphragm FA, the interval  $D_{11}$  between the diaphragm FA and the third group optical system G3, and the interval  $D_{19}$  between the third group optical system G3 and the
- 10   fourth group optical system G4 are variable, and these variable intervals  $D_5$ ,  $D_{10}$ ,  $D_{11}$ , and  $D_{19}$  are changed as shown in the following table, accompanying zooming.

**Table36** Variable interval

	Wide-angle end	Mean focal length	Telephoto end
f	5.80	17.40	29.00
$D_5$	1.20	17.54	21.68
$D_{10}$	21.48	5.14	1.00
$D_{11}$	8.69	4.60	1.00
$D_{19}$	2.07	5.23	9.18

- 15            The numerical values according to the respective conditional expressions of the present invention in example 2-1 are as shown in the following table, and within the range of the respective conditional expressions or values close to the range.

Numerical values in the conditional expressions

$$N_{c2} (N_{15-16})=1.48749$$

$$v_{c2} (v_{15-16})=70.44$$

$$N_{c1} (N_{14-15})=1.74950$$

5  $v_{c1} (v_{14-15})=35.04$

$$N_{c3} (N_{16-17})=1.69895$$

$$v_{c3} (v_{16-17})=30.05$$

$$R_{c2}/R_{c4}(R_{15}/R_{17})=0.975 (=10.996/11.275)$$

Fig. 23 is a schematic diagram of an optical system of example  
10 2-5 of a zoom lens according to the present invention. The zoom lens  
includes a first lens E1, a second lens E2, a third lens E3, a fourth lens  
E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8,  
a ninth lens E9, a tenth lens E10, an eleventh lens E11, a twelfth lens  
E12, and a diaphragm FA. In this case, the first to the third lenses E1  
15 to E3 constitute the first group optical system G1, the fourth to the sixth  
lenses E4 to E6 constitute the second group optical system G2, the  
seventh to the eleventh lenses E7 to E11 constitute the third group  
optical system G3, and the twelfth lens E12 constitutes the fourth group  
optical system G4.

20 The respective lenses are supported by an appropriate common  
support frame or the like for each lens group, and at the time of  
zooming, each group optical system integrally operates. The  
respective reference signs in Fig. 23 are used independently for each  
example as described previously. Therefore, even when a common  
25 reference sign is given, it is not always a common configuration to other



examples.

For example, the first lens E1, the second lens E2, the third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the diaphragm FA, the seventh lens E7, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, and the twelfth lens E12 are arranged in order from the object side of a subject or the like, and an image is formed at the back of the twelfth lens E12.

The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3 is a positive meniscus lens formed in a convex shape on the object side. The first lens E1 and the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

The fourth lens E4 is a negative meniscus lens formed in a convex shape on the object side, the fifth lens E5 is a negative lens including a double-concave lens, and the sixth lens E6 is a positive lens including a double-convex lens. The fifth lens E5 and the sixth lens E6 form a densely cemented doublet, and the second group optical system G2 formed of the fourth to the sixth lenses E4 to E6 exhibits a negative focal length as a whole.

The seventh lens E7 is a positive lens including a double-convex lens, the eighth lens E8 is a negative meniscus lens formed in a convex shape on the object side, the ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a negative lens including a

double-concave lens, and the eleventh lens E11 is a positive lens including a double-convex lens. The eighth to the tenth lenses E8 to E10 form a densely cemented triplet, and the third group optical system G3 formed of the seventh to the eleventh lenses E7 to E11 exhibits a  
5 positive focal length as a whole. The twelfth lens E12 is a positive meniscus lens formed in a convex shape on the object side and only the twelfth lens E12 forms the fourth group optical system G4. The diaphragm FA arranged between the second group optical system G2 and the third group optical system G3 makes a distance from the  
10 second group optical system G2 and a distance from the third group optical system G3 variable.

The sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second group optical system G2, and the twelfth surface, being a surface on the  
15 object side of the seventh lens E7 located closest to the object side in the third group optical system G3, the twentieth surface, being a surface on the object side of the twelfth lens E12 that forms the fourth group optical system G4 are respectively aspheric surfaces.

Accompanying zooming between the wide-angle end, that is, the  
20 short focal end, and the telephoto end, that is, the long focal end, the second group optical system G2 shifts from the image surface side toward the object side, the third group optical system G3 that mainly takes on a zooming function and an image-surface compensating function shifts from the image surface side toward the object side, and  
25 the fourth group optical system G4 is fixed in this case, but may shift to

mainly compensate the shift of the image surface accompanying to the shifts of the second group optical system G2 and the third group optical system G3.

5 In example 2-5, the focal length  $f$  of the whole system, the  $F$  number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=5.80$  to  $17.30$ ,  $F=2.81$  to  $4.20$ , and  $\omega=40.90$  to  $14.70$ . The optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table.

**Table37** Optical characteristics

Surface number	R	D	N d	$\nu$ d
1	120. 000	1. 00	1. 84666	23. 78
2	47. 947	3. 47	1. 77250	49. 62
3	777. 800	0. 10		
4	25. 000	3. 40	1. 62041	60. 34
5	80. 692	(Variable)		
6 (Aspheric surface)	47. 194	1. 00	1. 71736	29. 50
7	5. 735	3. 80		
8	-15. 615	1. 00	1. 51680	64. 20
9	7. 676	3. 03	1. 75520	27. 53
10	-591. 000	(Variable)		
11 (Diaphragm)	0. 000	(Variable)		
12 (Aspheric surface)	10. 480	3. 64	1. 62041	60. 34
13	-19. 154	0. 10		
14	11. 513	0. 80	1. 71736	29. 50
15	7. 087	4. 89	1. 51680	64. 20
16	-27. 000	0. 80	1. 75520	27. 53
17	6. 348	0. 50		
18	9. 108	2. 40	1. 48749	70. 44
19	-130. 567	(Variable)		
20 (Aspheric surface)	11. 607	2. 04	1. 60342	38. 01
21	30. 000			

The respective optical surfaces on the sixth surface, the twelfth surface, and the twentieth surface, described as "aspheric surface" in Table 37, are respectively aspheric surfaces, and parameters relating to the expression (26) on each aspheric surface are as follows.

5	Aspheric surface: the sixth surface
	$K=0$
	$A_4=5.23322 \times 10^{-5}$
	$A_6=-1.06487 \times 10^{-6}$
	$A_8=1.53041 \times 10^{-8}$
10	$A_{10}=-1.05107 \times 10^{-10}$
	Aspheric surface: the twelfth surface
	$K=0$
	$A_4=-2.36271 \times 10^{-4}$
	$A_6=8.22279 \times 10^{-7}$
15	$A_8=-2.66532 \times 10^{-8}$
	$A_{10}=1.51637 \times 10^{-10}$
	Aspheric surface: the twentieth surface
	$K=0$
	$A_4=-2.13837 \times 10^{-4}$
20	$A_6=1.02617 \times 10^{-5}$
	$A_8=-4.96891 \times 10^{-7}$
	$A_{10}=1.33335 \times 10^{-8}$

The interval  $D_5$  between the first group optical system G1 and the second group optical system G2, the interval  $D_{10}$  between the second group optical system G2 and the diaphragm FA, the interval  $D_{11}$

between the diaphragm FA and the third group optical system G3, and the interval  $D_{19}$  between the third group optical system G3 and the fourth group optical system G4 are variable, and these variable intervals  $D_5$ ,  $D_{10}$ ,  $D_{11}$ , and  $D_{19}$  are changed as shown in the following table, accompanying zooming.

**Table38** Variable interval

	Wide-angle end	Mean focal length	Telephoto end
$f$	5.80	11.60	17.30
$D_5$	1.20	8.30	10.70
$D_{10}$	10.50	3.40	1.00
$D_{11}$	6.02	3.39	1.00
$D_{19}$	2.00	2.49	2.27

The numerical values according to the respective conditional expressions of the present invention in example 2-5 are as shown in the following table, and within the range of the respective conditional expressions.

Numerical values in the conditional expressions

$$N_{c2} (N_{15-16})=1.51680$$

$$v_{c2} (v_{15-16})=64.20$$

$$N_{c1} (N_{14-15})=1.71736$$

$$v_{c1} (v_{14-15})=29.50$$

$$N_{c3} (N_{16-17})=1.75520$$

$$v_{c3} (v_{16-17})=27.53$$

$$R_{c2}/R_{c4}(R_{15}/R_{17})=1.116 (=7.087/6.348)$$

Fig. 24 is a schematic diagram of an optical system of example 2-6 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a twelfth lens E12, a diaphragm FA, and an optical filter OF. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the sixth lenses E4 to E6 constitute the second group optical system G2, the seventh to the eleventh lenses E7 to E11 constitute the third group optical system G3, and the twelfth lens E12 constitutes the fourth group optical system G4.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. The respective reference signs in Fig. 24 are used independently for each example as described previously. Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

For example, the first lens E1, the second lens E2, the third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the diaphragm FA, the seventh lens E7, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, the twelfth lens E12, and the optical filter OF are arranged in order from the object side of a

subject or the like, and an image is formed at the back of the optical filter OF.

The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3 is a positive meniscus lens formed in a convex shape on the object side. The first lens E1 and the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

The fourth lens E4 is a negative lens including a double-concave lens, the fifth lens E5 is also a negative lens including a double-concave lens, and the sixth lens E6 is a positive lens including a double-convex lens. The fifth lens E5 and the sixth lens E6 form a densely cemented doublet, and the second group optical system G2 formed of the fourth to the sixth lenses E4 to E6 exhibits a negative focal length as a whole.

The seventh lens E7 is a positive lens including a double-convex lens, the eighth lens E8 is a negative meniscus lens formed in a convex shape on the object side, the ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a negative lens including a double-concave lens, and the eleventh lens E11 is a positive lens including a double-convex lens. The eighth to the tenth lenses E8 to E10 form a densely cemented triplet, and the third group optical system G3 formed of the seventh to the eleventh lenses E7 to E11 exhibits a positive focal length as a whole. The twelfth lens E12 is a positive



lens including a double-convex lens and only the twelfth lens E12 that forms the fourth group optical system G4.

The diaphragm FA arranged between the second group optical system G2 and the third group optical system G3 makes a distance  
5 from the second group optical system G2 and a distance from the third group optical system G3 variable. The optical filter OF arranged on a side of image surface of the twelfth lens E12 of the fourth group optical system G4 is integrally retained with the fourth group optical system G4 and includes various optical filtering functions.

10 The sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second group optical system G2, and the twelfth surface, being a surface on the object side of the seventh lens E7 located closest to the object side in the third group optical system G3, the twentieth surface, being a  
15 surface on the object side of the twelfth lens E12 that forms the fourth group optical system G4 are respectively aspheric surfaces.

Accompanying zooming between the wide-angle end, that is, the short focal end, and the telephoto end, that is, the long focal end, the second group optical system G2 shifts from the image surface side  
20 toward the object side, the third group optical system G3 that mainly takes on a zooming function and an image-surface compensating function shifts from the image surface side toward the object side, and the fourth group optical system G4 is fixed in this case, but may shift to mainly compensate the shift of the image surface accompanying to the  
25 shifts of the second group optical system G2 and the third group optical

system G3.

In example 2-6, the focal length  $f$  of the whole system, the  $F$  number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=5.80$  to  $17.30$ ,  $F=2.89$  to  $4.02$ , and  $\omega=39.93$  to  $14.65$ . The  
5 optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table.

**Table39** Optical characteristics

Surface number	R	D	N d	$\nu$ d
1	120.000	1.40	1.84666	23.78
2	47.947	4.00	1.77250	49.62
3	777.800	0.10		
4	38.000	3.13	1.74400	44.90
5	157.162	(Variable)		
6 (Aspheric surface)	-107.942	1.00	1.74950	35.04
7	7.565	4.95		
8	-11.990	1.40	1.48749	70.44
9	13.998	4.38	1.74950	35.04
10	-25.914	(Variable)		
11 (Diaphragm)	$\infty$	(Variable)		
12 (Aspheric surface)	10.269	3.34	1.74950	35.04
13	-85.882	0.10		
14	22.337	0.80	1.69895	30.05
15	8.100	5.64	1.51680	64.20
16	-7.056	0.80	1.75520	27.53
17	9.105	0.71		
18	22.991	2.35	1.62041	60.34
19	-22.340	(Variable)		
20 (Aspheric surface)	17.024	2.53	1.74400	44.90
21	-58.471	3.16		
22	$\infty$	3.26	1.51680	64.20
23	$\infty$			

The respective optical surfaces on the sixth surface, the twelfth surface, and the twentieth surface, described as "aspheric surface" in Table 39, are respectively aspheric surfaces, and parameters relating to the expression (26) on each aspheric surface are as follows.

5	Aspheric surface: the sixth surface
	$K=0$
	$A_4=1.10558 \times 10^{-4}$
	$A_6=-1.01970 \times 10^{-6}$
	$A_8=7.93490 \times 10^{-9}$
10	$A_{10}=-3.49749 \times 10^{-11}$
	Aspheric surface: the twelfth surface
	$K=0$
	$A_4=-7.70888 \times 10^{-5}$
	$A_6=2.55732 \times 10^{-7}$
15	$A_8=-7.94450 \times 10^{-10}$
	$A_{10}=-6.13339 \times 10^{-11}$
	Aspheric surface: the twentieth surface
	$K=0$
	$A_4=-1.76923 \times 10^{-5}$
20	$A_6=3.83822 \times 10^{-7}$
	$A_8=-8.16788 \times 10^{-9}$
	$A_{10}=1.40087 \times 10^{-8}$

The interval  $D_5$  between the first group optical system G1 and the second group optical system G2, the interval  $D_{10}$  between the second group optical system G2 and the diaphragm FA, the interval  $D_{11}$

between the diaphragm FA and the third group optical system G3, and the interval  $D_{19}$  between the third group optical system G3 and the fourth group optical system G4 are variable, and these variable intervals  $D_5$ ,  $D_{10}$ ,  $D_{11}$ , and  $D_{19}$  are changed as shown in the following table, accompanying zooming.

**Table40** Variable interval

	Wide-angle end	Mean focal length	Telephoto end
$f$	5.80	11.60	17.30
$D_5$	1.20	8.17	15.14
$D_{10}$	14.94	7.97	1.00
$D_{11}$	7.68	1.71	1.00
$D_{19}$	2.00	8.01	6.61

The numerical values according to the respective conditional expressions of the present invention in example 2-6 are as shown in the following table, and within the range of the respective conditional expressions.

Numerical values in the conditional expressions

$$N_{c2} (N_{15-16})=1.51680$$

$$v_{c2} (v_{15-16})=64.20$$

$$N_{c1} (N_{14-15})=1.69895$$

$$v_{c1} (v_{14-15})=30.05$$

$$N_{c3} (N_{16-17})=1.75520$$

$$v_{c3} (v_{16-17})=27.53$$

$$R_{c2}/R_{c4}(R_{15}/R_{17})=0.890 (=8.100/9.105)$$

Fig. 25 is an aberration curve at the short focal end of the zoom lens in example 2-1, Fig. 26 is an aberration curve at the mean focal length of the zoom lens in example 2-1, and Fig. 27 is an aberration  
5 curve at the long focal end of the zoom lens in example 2-1.

Fig. 28 is an aberration curve at the short focal end of the zoom lens in example 2-2, Fig. 29 is an aberration curve at the mean focal length of the zoom lens in example 2-2, and Fig. 30 is an aberration curve at the long focal end of the zoom lens in example 2-2. Likewise,  
10 Fig. 31 is an aberration curve at the short focal end of the zoom lens in example 2-3, Fig. 32 is an aberration curve at the mean focal length of the zoom lens in example 2-3, and Fig. 33 is an aberration curve at the long focal end of the zoom lens in example 2-3. Fig. 34 is an aberration curve at the short focal end of the zoom lens in example 2-4,  
15 Fig. 35 is an aberration curve at the mean focal length of the zoom lens in example 2-4, and Fig. 36 is an aberration curve at the long focal end of the zoom lens in example 2-4. Fig. 37 is an aberration curve at the short focal end of the zoom lens in example 2-5, Fig. 38 is an aberration curve at the mean focal length of the zoom lens in example  
20 2-5, and Fig. 39 is an aberration curve at the long focal end of the zoom lens in example 2-5.

Fig. 40 is an aberration curve at the short focal end of the zoom lens in example 2-6, Fig. 41 is an aberration curve at the mean focal length of the zoom lens in example 2-6, and Fig. 42 is an aberration  
25 curve at the long focal end of the zoom lens in example 2-6. In the

aberration curves from Fig. 25 to Fig. 42, a solid line in the diagram illustrating spherical aberration expresses spherical aberration, and a broken line expresses sine condition, and a solid line in the diagram illustrating astigmatism expresses a sagittal image surface and a broken line expresses a meridional image surface. From these aberration curves, it is seen that excellent characteristics can be obtained from the respective examples. If a camera is constructed by using the zoom lens shown in these examples as the shooting lens, a small and high quality camera with a wide angle of view can be realized.

10 If a mobile information terminal is constructed by using the zoom lens shown in these examples as the shooting lens in the camera unit, a mobile information terminal having a small and high quality camera with a wide angle of view can be realized.

Next, several examples that shows specific configuration and numerical examples of a zoom lens according to a fifth embodiment of the present invention will be explained in detail. Specific configuration and numerical examples are shown in example 3, as an example of the zoom lens according to the fifth embodiment of the present invention. In example 3, the aberrations of the zoom lens are sufficiently corrected, and correspondence to the photodetector with 3,000,000 to 5,000,000 pixels becomes possible. It will be obvious from the examples below, that excellent imaging performance can be ensured, while achieving sufficient miniaturization, by forming the zoom lens as shown in the fifth embodiment.

25 In example 3, various signs as described below are used.

- f: Focal length of the whole system
- F: F number
- $\omega$ : Half angle of view
- R: Radius of curvature of each surface
- 5 D: Spacing
- $N_d$ : Refractive index with respect to d ray
- $v_d$ : Abbe constant with respect to d ray
- K: Conical constant of the aspheric surface
- $A_4$ : Fourth coefficient of the aspheric surface
- 10  $A_6$ : Sixth coefficient of the aspheric surface
- $A_8$ : Eighth coefficient of the aspheric surface
- $A_{10}$ : Tenth coefficient of the aspheric surface
- Wide: Short focal length
- Mean: Medium focal length
- 15 Tele: Long focal length

However, the aspheric surface used herein is defined by the following expression, when it is assumed that a reciprocal of a paraxial radius of curvature (paraxial curvature) is C, and the height from the optical axis is H.

$$20 \quad X = \frac{CH^2}{1 + \sqrt{(1 - (1 + K)C^2H^2)}} + A_4 \cdot Y^4 + A_6 \cdot Y^6 + A_8 \cdot Y^8 + A_{10} \cdot Y^{10} \quad (26)$$

In the numerical examples below, E-XY stands for  $10^{-XY}$ . In the aberration diagram explained below, a solid line in the diagram illustrating spherical aberration expresses spherical aberration, and a broken line expresses sine condition, and a solid line in the diagram



illustrating astigmatism expresses a sagittal image surface and a broken line expresses a meridional image surface. Further, in the respective aberration diagrams, d ray (587.56 nanometers) and g ray (435.83 nanometers) are illustrated.

5            Fig. 43 is a schematic diagram of an optical system of example 3-1 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a twelfth lens  
10 E12, a diaphragm FA, an optical filter OF, and a cover glass CG. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the seventh lenses E4 to E7 constitute the second group optical system G2, the eighth lens E8 constitutes the third group optical system G3, the ninth to the eleventh lenses E9 to  
15 E11 constitute the fourth group optical system G4, and the twelfth lens E12 constitutes the fifth group optical system G5.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. In Fig. 43,  
20 surface numbers that are assigned to each optical surface are shown for reference. The respective reference signs in Fig. 43 are used independently for each example in order to avoid complexity due to an increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common  
25 configuration to other examples.

For example, the first lens E1, the second lens E2, the third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the seventh lens E7, the diaphragm FA, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, the twelfth lens E12, an  
5 thirteenth E13, the optical filter OF, and the cover glass CG are arranged in order from the object side of a subject or the like to the image-surface side, and an image is formed at the back of the cover glass CG.

The first lens E1 is a negative meniscus lens formed in a convex  
10 shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side; and the third lens E3 is a positive lens including a double-convex lens. The first lens E1 and the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3  
15 exhibits a positive focal length as a whole.

The fourth lens E4 is a negative lens including a double-concave lens, the fifth lens E5 is a negative lens including a double-concave lens, the sixth lens E6 is a positive lens including a double-convex lens, and the seventh lens E7 is a negative lens including a double-concave  
20 lens. The second group optical system G2 formed of the fourth to the seventh lenses E4 to E7 exhibits a negative focal length as a whole.

The eighth lens E8 is a positive meniscus lens formed in a convex shape on the object side and only the eighth lens E8 forms the third group optical system G3 that exhibits a positive focal length. The  
25 ninth lens E9 is a positive lens including a double-convex lens, the

tenth lens E10 is a positive lens including a double-convex lens, and the eleventh lens E11 is a negative lens including a double-concave lens. The tenth to the eleventh lenses E10 to E11 form a densely cemented doublet, and the fourth group optical system G4 formed of the ninth to the eleventh lenses E9 to E11 exhibits a positive focal length as  
5 a whole. The twelfth lens E12 is a positive lens including a double-convex lens and only the twelfth lens E12 forms the fifth group optical system G5 that exhibits a positive focal length.

The diaphragm FA arranged between the second group optical  
10 system G2 and the third group optical system G3 is integrally retained with the third group optical system G3 while keeping the distance from the third group optical system G3 constant.

On a side of the image surface of the twelfth lens E12 of the fifth group optical system G5, the optical filter OF that includes various  
15 optical filtering functions and the cover glass CG that protects an input surface of a solid image element are arranged in order toward the image-surface side and integrally retained with the solid image element.

The fourth surface, being a surface on the object side of the third lens E3 located closest to the image-surface side in the first group  
20 optical system G1, the sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second group optical system G2, the thirteenth surface, being a surface on the object side of the eighth lens E8 that forms the third group optical system G3, the fifteenth surface, being a surface on the object side of  
25 the ninth lens E9 located closest to the object side in the fourth group

optical system G4, and the twentieth surface, being a surface on the object side of the twelfth lens E12 that forms the fifth group optical system G5 are respectively aspheric surfaces.

5 In example 3-1, the focal length  $f$  of the whole system, the F number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=7.404$  to  $71.820$ ,  $F=3.2$  to  $4.40$ , and  $\omega=33.497$  to  $3.705$ . The optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table.

**Table41** Optical characteristics

Sur-face	R	D	N <sub>d</sub>	V <sub>d</sub>	Note
1	89.755	1.200	1.78300	30.7	First lens
2	27.999	4.458	1.61900	60.3	Second lens
3	227.885	0.100			
4	26.060	4.801	1.61700	60.4	Third lens
5	-11645.225	d 1			
6	-279.679	1.000	1.83200	37.3	Fourth lens
7	10.975	3.231			
8	-61.442	0.800	1.54100	65.3	Fifth lens
9	10.925	3.597	1.71700	29.5	Sixth lens
10	-15.956	0.800	1.77300	49.6	Seventh lens
11	42.210	d 2			
12	Diaphragm	1.000			
13	11.846	1.284	1.48700	70.4	Eighth lens
14	20.211	d 3			
15	13.910	2.410	1.50000	68.9	Ninth lens
16	-25.091	0.100			
17	13.689	3.374	1.69100	54.2	Tenth lens
18	-18.625	3.500	1.78700	33.0	Eleventh lens
19	7.393	d 4			
20	15.210	1.622	1.48700	70.4	Twelfth lens
21	-281.555	d 5			
22	Plane	0.927	1.54900	69.3	Filter
23	Plane	0.800			
24	Plane	0.500	1.50000	64.0	cover glass
25	Plane				

The respective optical surfaces on the fourth surface, the sixth surface, the thirteenth surface, the fifteenth surface, and the twentieth surface in Table 41 are respectively aspheric surfaces, and parameters relating to the expression (26) on each aspheric surface are as follows.

**Table42** Coefficient of aspheric surface

	K	$A_4$	$A_6$	$A_8$	$A_{10}$
4	-0.149	-0.120E-05	-0.192E-08	-0.176E-11	-0.448E-14
6	326.153	0.264E-04	-0.159E-06	0.140E-08	-0.568E-11
13	-2.285	0.104E-03	-0.457E-06	-0.170E-07	0.151E-11
15	-0.902	-0.424E-04	0.835E-07	0.356E-08	-0.575E-10
20	-0.226	-0.612E-06	-0.277E-06	0.593E-07	-0.125E-08

5 The interval d1 between the first group optical system G1 and the second group optical system G2, the interval d2 between the second group optical system G2 and the diaphragm FA, the interval d3 between the third group optical system G3 and the fourth group optical system G4, the interval d4 between the fourth group optical system G4 and the fifth group optical system G5, and the interval d5 between the fifth group optical system G5 and the optical filter OF are variable, and these variable intervals d1, d2, d3, d4, and d5 are changed as shown in the following table, corresponding to the focal length f of the whole system, accompanying zooming.

10

15

**Table43** Variable intervals

	f	d 1	d 2	d 3	d 4	d 5
Wide	7.404	0.532	22.110	12.600	3.020	2.407
Mean	23.917	14.053	8.569	7.257	5.514	2.998
Tele	71.820	21.478	1.164	1.000	17.500	1.700

The parameter values according to the conditional expression (17) of the present invention in example 3-1 are as shown in the following table, and within the range of the conditional expression.

**Table44** Parameter values in the conditional expression

$R_{C2}/R_{C4}$	0.259
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The aberration diagrams at the wide-angle end (short focal end), the mean focal length, and the telephoto end (long focal end) according to example 3-1 are respectively illustrated in Fig. 47 to Fig. 49.

Fig. 44 is a schematic diagram of an optical system of example 3-2 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a twelfth lens E12, a diaphragm FA, an optical filter OF, and a cover glass CG. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the seventh lenses E4 to E7 constitute the second group optical system G2, the eighth lens E8 constitutes the

third group optical system G3, the ninth to the eleventh lenses E9 to E11 constitute the fourth group optical system G4, and the twelfth lens E12 constitutes the fifth group optical system G5.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. In Fig. 44, parts of surface numbers that are assigned to each optical surface are shown for reference. The respective reference signs in Fig. 44 are used independently for each example as described previously.

Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

For example, the first lens E1, the second lens E2, the third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the seventh lens E7, the diaphragm FA, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, the twelfth lens E12, an thirteenth E13, the optical filter OF, and the cover glass CG are arranged in order from the object side of a subject or the like to the image-surface side, and an image is formed at the back of the cover glass CG.

The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3 is a positive lens including a double-convex lens. The first lens E1 and the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3



exhibits a positive focal length as a whole.

The fourth lens E4 is a negative lens including a double-concave lens, the fifth lens E5 is a negative lens including a double-concave lens, the sixth lens E6 is a positive lens including a double-convex lens,  
5 and the seventh lens E7 is a negative lens including a double-concave lens. The second group optical system G2 formed of the fourth to the seventh lenses E4 to E7 exhibits a negative focal length as a whole.

The eighth lens E8 is a positive meniscus lens formed in a convex shape on the object side and only the eighth lens E8 forms the  
10 third group optical system G3 that exhibits a positive focal length.

The ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a positive lens including a double-convex lens, and the eleventh lens E11 is a negative lens including a double-concave lens. The tenth to the eleventh lenses E10 to E11  
15 form a densely cemented doublet, and the fourth group optical system G4 formed of the ninth to the eleventh lenses E9 to E11 exhibits a positive focal length as a whole. The twelfth lens E12 is a positive lens including a double-convex lens and only the twelfth lens E12 forms the fifth group optical system G5 that exhibits a positive focal length.

20 The diaphragm FA arranged between the second group optical system G2 and the third group optical system G3 is integrally retained with the third group optical system G3 while keeping the distance from the third group optical system G3 constant.

On a side of the image surface of the twelfth lens E12 of the fifth  
25 group optical system G5, the optical filter OF that includes various

optical filtering functions and the cover glass CG that protects an input surface of a solid image element are arranged in order toward the image-surface side and retained integrally with the solid image element.

5       The fourth surface, being a surface on the object side of the third lens E3 located closest to the image-surface side in the first group optical system G1, the sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second group optical system G2, the thirteenth surface, being a surface on the object side of the eighth lens E8 that forms the third group optical system G3, the fifteenth surface, being a surface on the object side of the ninth lens E9 located closest to the object side in the fourth group optical system G4, and the twentieth surface, being a surface on the object side of the twelfth lens E12 that forms the fifth group optical system G5 are respectively aspheric surfaces.

15       In example 3-2, the focal length  $f$  of the whole system, the F number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=7.400$  to  $71.776$ ,  $F=3.200$  to  $4.400$ , and  $\omega=33.512$  to  $3.707$ . The optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table.

**Table45** Optical characteristics

Sur-face	R	D	N <sub>d</sub>	V <sub>d</sub>	Note
1	91.074	1.200	1.78700	31.0	First lens
2	28.167	4.266	1.61400	60.6	Second lens
3	235.621	0.100			
4	26.060	4.801	1.61500	60.6	Third lens
5	-916.538	d 1			
6	-209.116	1.000	1.81900	32.8	Fourth lens
7	11.17657	3.202			
8	-51.636	0.800	1.57900	62.7	Fifth lens
9	11.809	2.899	1.80100	25.1	Sixth lens
10	-29.084	0.800	1.83500	43.0	Seventh lens
11	40.965	d 2			
12	Diaphragm	1.000			
13	11.822	1.291	1.48800	70.3	Eighth lens
14	20.211	d 3			
15	14.054	2.520	1.50100	68.9	Ninth lens
16	-24.574	0.100			
17	14.024	3.451	1.69000	54.3	Tenth lens
18	-18.0889	3.500	1.78700	33.0	Eleventh lens
19	7.486	d 4			
20	15.258	3.555	1.48700	70.4	Twelfth lens
21	-367.955	d 5			
22	Plane	0.927	1.54900	69.3	Filter
23	Plane	0.800			
24	Plane	0.500	1.50000	64.0	cover glass
25	Plane				

The respective optical surfaces on the fourth surface, the sixth surface, the thirteenth surface, the fifteenth surface, and the twentieth surface in Table 45 are respectively aspheric surfaces, and parameters relating to the expression (26) on each aspheric surface are as follows.

**Table46** Coefficient of aspheric surface

	K	$A_4$	$A_6$	$A_8$	$A_{10}$
4	-0.152	-0.123E-05	-0.190E-08	-0.138E-11	-0.478E-14
6	316.273	0.266E-04	-0.157E-06	0.184E-08	-0.722E-11
13	-2.305	0.103E-03	-0.450E-06	-0.942E-09	0.593E-11
15	-0.892	-0.419E-04	0.760E-07	0.271E-08	-0.480E-10
20	-0.298	-0.335E-05	-0.376E-06	0.655E-07	-0.140E-08

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The interval d1 between the first group optical system G1 and the second group optical system G2, the interval d2 between the second group optical system G2 and the diaphragm FA, the interval d3 between the third group optical system G3 and the fourth group optical system G4, the interval d4 between the fourth group optical system G4 and the fifth group optical system G5, and the interval d5 between the fifth group optical system G5 and the optical filter OF are variable, and these variable intervals d1, d2, d3, d4, and d5 are changed as shown in the following table, corresponding to the focal length f of the whole system, accompanying zooming.

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**Table47** Variable intervals

	f	d 1	d 2	d 3	d 4	d 5
Wide	7.399	0.543	22.429	13.115	1.992	2.407
Mean	23.898	14.135	8.818	7.332	5.373	2.998
Tele	71.776	21.801	1.171	1.000	17.607	1.700

The parameter values according to the conditional expression (17) of the present invention in example 3-2 are as shown in the following table, and within the range of the conditional expression.

**Table48** Parameter values in the conditional expression

$R_{C2}/R_{C4}$	0.288
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The aberration diagrams at the wide-angle end (short focal end), the mean focal length, and the telephoto end (long focal end) according to example 3-2 are respectively illustrated in Fig. 50 to Fig. 52.

Fig. 45 is a schematic diagram of an optical system of example 3-3 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a twelfth lens E12, a diaphragm FA, an optical filter OF, and a cover glass CG. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the seventh lenses E4 to E7 constitute the second group optical system G2, the eighth lens E8 constitutes the

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third group optical system G3, the ninth to the eleventh lenses E9 to E11 constitute the fourth group optical system G4, and the twelfth lens E12 constitutes the fifth group optical system G5.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of  
5 zooming, each group optical system integrally operates. In Fig. 45, parts of surface numbers that are assigned to each optical surface are shown for reference. The respective reference signs in Fig. 45 are used independently for each example, as described previously.  
10 Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

For example, the first lens E1, the second lens E2, the third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the seventh lens E7, the diaphragm FA, the eighth lens E8, the ninth lens E9, the  
15 tenth lens E10, the eleventh lens E11, the twelfth lens E12, an thirteenth E13, the optical filter OF, and the cover glass CG are arranged in order from the object side of a subject or the like to the image-surface side, and an image is formed at the back of the cover glass CG.

20 The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3 is a positive meniscus lens formed in a convex shape on the object side. The first lens E1 and the second lens E2 form a densely cemented  
25 doublet, and the first group optical system G1 formed of the first to the

third lenses E1 to E3 exhibits a positive focal length as a whole.

The fourth lens E4 is a negative lens including a double-concave lens, the fifth lens E5 is a negative lens including a double-concave lens, the sixth lens E6 is a positive lens including a double-convex lens,  
5 and the seventh lens E7 is a negative lens including a double-concave lens. The second group optical system G2 formed of the fourth to the seventh lenses E4 to E7 exhibits a negative focal length as a whole.

The eighth lens E8 is a positive meniscus lens formed in a convex shape on the object side and only the eighth lens E8 forms the  
10 third group optical system G3 that exhibits a positive focal length. The ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a positive lens including a double-convex lens, and the eleventh lens E11 is a negative lens including a double-concave lens. The tenth to the eleventh lenses E10 to E11 form a densely  
15 cemented doublet, and the fourth group optical system G4 formed of the ninth to the eleventh lenses E9 to E11 exhibits a positive focal length as a whole. The twelfth lens E12 is a positive meniscus lens formed in a convex shape on the object side and only the twelfth lens E12 forms the fifth group optical system G5 that exhibits a positive focal length.

20 The diaphragm FA arranged between the second group optical system G2 and the third group optical system G3 is integrally retained with the third group optical system G3 while keeping the distance from the third group optical system G3 constant.

On a side of the image surface of the twelfth lens E12 of the fifth  
25 group optical system G5, the optical filter OF that includes various

optical filtering functions and the cover glass CG that protects an input surface of a solid image element are arranged in order toward the image-surface side and retained integrally with the solid image element.

5       The fourth surface, being a surface on the object side of the third lens E3 located closest to the image-surface side in the first group optical system G1, the sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second group optical system G2, the thirteenth surface, being a surface on the object side of the eighth lens E8 that forms the third group optical  
10       system G3, the fifteenth surface, being a surface on the object side of the ninth lens E9 located closest to the object side in the fourth group optical system G4, and the twentieth surface, being a surface on the object side of the twelfth lens E12 that forms the fifth group optical system G5 are respectively aspheric surfaces.

15       In example 3-3, the focal length  $f$  of the whole system, the F number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=7.4$  to  $71.78$ ,  $F=3.1$  to  $4.3$ , and  $\omega=33.511$  to  $3.707$ . The optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table.



**Table49** Optical characteristics

Sur-face	R	D	N <sub>d</sub>	V <sub>d</sub>	Note
1	104.665	1.200	1.78400	29.5	First lens
2	29.362	4.450	1.62000	60.3	Second lens
3	360.264	0.100			
4	25.711	4.956	1.62000	60.2	Third lens
5	6466.354	d 1			
6	-319.910	1.000	1.77700	49.0	Fourth lens
7	10.529	3.482			
8	-44.997	0.800	1.58300	62.4	Fifth lens
9	10.693	3.955	1.75000	35.0	Sixth lens
10	-13.121	0.800	1.77300	49.6	Seventh lens
11	44.864	d 2			
12	Diaphragm	1.000			
13	11.641	1.300	1.48700	70.4	Eighth lens
14	19.475	d 3			
15	13.988	2.548	1.50200	68.8	Ninth lens
16	-24.250	0.100			
17	13.903	3.198	1.69300	54.1	Tenth lens
18	-18.843	3.500	1.78800	33.8	Eleventh lens
19	7.494	d 4			
20	14.815	1.587	1.48700	70.4	Twelfth lens
21	967.954	d 5			
22	Plane	0.927	1.54900	69.3	Filter
23	Plane	0.800			
24	Plane	0.500	1.50000	64.0	cover glass
25	Plane				

The respective optical surfaces on the fourth surface, the sixth surface, the thirteenth surface, the fifteenth surface, and the twentieth surface in Table 49 are respectively aspheric surfaces, and parameters relating to the expression (26) on each aspheric surface are as follows.

**Table50** Coefficient of aspheric surface

	K	$A_4$	$A_6$	$A_8$	$A_{10}$
4	-0.156	-0.126E-05	-0.207E-08	-0.169E-11	-0.584E-14
6	419.293	0.265E-04	-0.217E-06	0.209E-08	-0.852E-11
13	-2.278	0.105E-03	-0.457E-06	-0.249E-08	0.678E-10
15	-0.898	-0.422E-04	0.783E-07	0.203E-08	-0.348E-10
20	-0.281	-0.295E-05	0.303E-07	0.563E-07	-0.131E-08

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The interval d1 between the first group optical system G1 and the second group optical system G2, the interval d2 between the second group optical system G2 and the diaphragm FA, the interval d3 between the third group optical system G3 and the fourth group optical system G4, the interval d4 between the fourth group optical system G4 and the fifth group optical system G5, and the interval d5 between the fifth group optical system G5 and the optical filter OF are variable, and these variable intervals d1, d2, d3, d4, and d5 are changed as shown in the following table, corresponding to the focal length f of the whole system, accompanying zooming.

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**Table51** Variable intervals

	f	d 1	d 2	d 3	d 4	d 5
Wide	7.4	0.531	21.530	12.868	1.705	2.407
Mean	23.9	13.684	8.357	7.309	4.922	2.998
Tele	71.780	20.916	1.166	1.000	18.194	1.7

The parameter values according to the conditional expression (17) of the present invention in example 3-3 are as shown in the following table, and within the range of the conditional expression.

**Table52** Parameter values in the conditional expression

$R_{C2}/R_{C4}$	0.238
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The aberration diagrams at the wide-angle end (short focal end), the mean focal length, and the telephoto end (long focal end) according to example 3-3 are respectively illustrated in Fig. 53 to Fig. 55.

Fig. 46 is a schematic diagram of an optical system of example 3-4 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a twelfth lens E12, a diaphragm FA, an optical filter OF, and a cover glass CG. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the seventh lenses E4 to E7 constitute the second group optical system G2, the eighth lens E8 constitutes the

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third group optical system G3, the ninth to the eleventh lenses E9 to E11 constitute the fourth group optical system G4, and the twelfth lens E12 constitutes the fifth group optical system G5.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of  
5 zooming, each group optical system integrally operates. In Fig. 46, parts of surface numbers that are assigned to each optical surface are shown for reference. The respective reference signs in Fig. 46 are used independently for each example, in order to avoid complexity due  
10 to an increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

For example, the first lens E1, the second lens E2, the third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the seventh  
15 lens E7, the diaphragm FA, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, the twelfth lens E12, an thirteenth E13, the optical filter OF, and the cover glass CG are arranged in order from the object side of a subject or the like to the image-surface side, and an image is formed at the back of the cover  
20 glass CG.

The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3 is a positive lens including a double-convex lens. The first lens E1 and  
25 the second lens E2 form a densely cemented doublet, and the first

group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

The fourth lens E4 is a negative lens including a double-concave lens, the fifth lens E5 is a negative lens including a double-concave lens, the sixth lens E6 is a positive lens including a double-convex lens, and the seventh lens E7 is a negative lens including a double-concave lens. The second group optical system G2 formed of the fourth to the seventh lenses E4 to E7 exhibits a negative focal length as a whole.

The eighth lens E8 is a positive meniscus lens formed in a convex shape on the object side and only the eighth lens E8 forms the third group optical system G3 that exhibits a positive focal length. The ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a positive lens including a double-convex lens, and the eleventh lens E11 is a negative lens including a double-concave lens. The tenth to the eleventh lenses E10 to E11 form a densely cemented doublet, and the fourth group optical system G4 formed of the ninth to the eleventh lenses E9 to E11 exhibits a positive focal length as a whole. The twelfth lens E12 is a positive meniscus lens formed in a convex shape on the object side and only the twelfth lens E12 forms the fifth group optical system G5 that exhibits a positive focal length.

The diaphragm FA arranged between the second group optical system G2 and the third group optical system G3 is integrally retained with the third group optical system G3 while keeping the distance from the third group optical system G3 constant.

On a side of the image surface of the twelfth lens E12 of the fifth

group optical system G5, the optical filter OF that includes various optical filtering functions and the cover glass CG that protects an input surface of a solid image element are arranged in order toward the image-surface side and retained integrally with the solid image element.

5           The fourth surface, being a surface on the object side of the third lens E3 located closest to the image-surface side in the first group optical system G1, the sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second group optical system G2, the thirteenth surface, being a surface on the  
10       object side of the eighth lens E8 that forms the third group optical system G3, the fifteenth surface, being a surface on the object side of the ninth lens E9 located closest to the object side in the fourth group optical system G4, and the twentieth surface, being a surface on the object side of the twelfth lens E12 that forms the fifth group optical  
15       system G5 are respectively aspheric surfaces.

          In example 3-4, the focal length  $f$  of the whole system, the F number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=7.4$  to  $71.774$ ,  $F=3.2$  to  $4.4$ , and  $\omega=33.511$  to  $3.707$ . The optical characteristics relating to the respective optical surfaces and the  
20       optical elements are as shown in the following table.

**Table53** Optical characteristics

Sur-face	R	D	N <sub>d</sub>	V <sub>d</sub>	Note
1	102.324	1.200	1.81000	32.4	First lens
2	28.720	4.340	1.62000	60.3	Second lens
3	316.900	0.100			
4	26.521	4.556	1.61600	60.5	Third lens
5	-1623.049	d 1			
6	-233.391	1.000	1.84300	28.4	Fourth lens
7	11.103	3.185			
8	-64.989	0.800	1.58700	62.1	Fifth lens
9	11.604	2.933	1.84700	23.8	Sixth lens
10	-33.164	0.800	1.83500	43.0	Seventh lens
11	34.007	d 2			
12	Diaphragm	1.000			
13	11.848	1.313	1.48700	70.4	Eighth lens
14	20.383	d 3			
15	14.12268	2.488	1.50600	68.4	Ninth lens
16	-24.665	0.100			
17	13.579	3.222	1.69300	54.1	Tenth lens
18	-18.727	3.500	1.78300	32.3	Eleventh lens
19	7.417	d 4			
20	13.963	1.565	1.48700	70.4	Twelfth lens
21	110.201	d 5			
22	Plane	0.927	1.54900	69.3	Filter
23	Plane	0.800			
24	Plane	0.500	1.50000	64.0	cover glass
25	Plane				

The respective optical surfaces on the fourth surface, the sixth surface, the thirteenth surface, the fifteenth surface, and the twentieth surface in Table 53 are respectively aspheric surfaces, and parameters relating to the expression (26) on each aspheric surface are as follows.

**Table54** Coefficient of aspheric surface

	K	$A_4$	$A_6$	$A_8$	$A_{10}$
4	-0.147	-0.117E-05	-0.181E-08	-0.163E-11	-0.400E-14
6	329.270	0.254E-04	-0.179E-06	0.211E-08	-0.967E-11
13	-2.312	0.103E-03	-0.438E-06	-0.849E-09	-0.616E-13
15	-0.886	-0.416E-04	0.505E-07	0.228E-08	-0.370E-10
20	-0.370	-0.244E-05	-0.388E-06	0.745E-07	-0.157E-08

The interval d1 between the first group optical system G1 and the second group optical system G2, the interval d2 between the second group optical system G2 and the diaphragm FA, the interval d3 between the third group optical system G3 and the fourth group optical system G4, the interval d4 between the fourth group optical system G4 and the fifth group optical system G5, and the interval d5 between the fifth group optical system G5 and the optical filter OF are variable, and these variable intervals d1, d2, d3, d4, and d5 are changed as shown in the following table, corresponding to the focal length f of the whole system, accompanying zooming.



**Table55** Variable intervals

	f	d 1	d 2	d 3	d 4	d 5
Wide	7.4	0.804	22.644	13.349	2.851	2.407
Mean	23.9	14.741	8.687	7.688	6.276	2.998
Tele	71.774	22.227	1.221	1.000	19.327	1.7

The parameter values according to the conditional expression (17) of the present invention in example 3-4 are as shown in the following table, and within the range of the conditional expression.

**Table56** Parameter values in the conditional expression

$R_{C2}/R_{C4}$	0.341
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The aberration diagrams at the wide-angle end (short focal end), the mean focal length, and the telephoto end (long focal end) according to example 3-4 are respectively illustrated in Fig. 56 to Fig. 58. In example 1 to example 3-4, as the lens material for all lenses, an optical glass that is chemically stable and does not contain any toxic substance such as lead or arsenic can be used, the materials can be recycled, without having water pollution due to waste fluid at the time of machining.

According to the fifth embodiment, a zoom lens, which is sufficiently small, can achieve a high magnification, and can obtain a high resolving power corresponding to the image capturing device with 3,000,000 to 5,000,000 pixels, a camera using the zoom lens as the

shooting optical system, and a mobile information terminal using the zoom lens as the shooting optical system in the camera unit can be provided.

Specific configuration and numerical examples are shown in example 3, as an example of the zoom lens according to the sixth embodiment of the present invention. In each example, the aberrations of the zoom lens are sufficiently corrected, and correspondence to the photodetector with 3,000,000 to 5,000,000 pixels becomes possible. It will be obvious from the examples below, that excellent imaging performance can be ensured, while achieving sufficient miniaturization, by forming the zoom lens as shown in the sixth embodiment.

In each example, various signs as described below are used.

f: Focal length of the whole system

15 F: F number

$\omega$ : Half angle of view

R: Radius of curvature of each surface

D: Spacing

$N_d$ : Refractive index with respect to d ray

20  $v_d$ : Abbe constant with respect to d ray

K: Conical constant of the aspheric surface

$A_4$ : Fourth coefficient of the aspheric surface

$A_6$ : Sixth coefficient of the aspheric surface

$A_8$ : Eighth coefficient of the aspheric surface

25  $A_{10}$ : Tenth coefficient of the aspheric surface

Wide: Short focal length

Mean: Medium focal length

Tele: Long focal length

However, the aspheric surface used herein is defined by the  
5 following expression, when it is assumed that a reciprocal of a paraxial  
radius of curvature (paraxial curvature) is C, and the height from the  
optical axis is H.

$$X = \frac{CH^2}{1 + \sqrt{1 - (1+K)C^2H^2}} + A_4 \cdot Y^4 + A_6 \cdot Y^6 + A_8 \cdot Y^8 + A_{10} \cdot Y^{10} \quad (26)$$

In the numerical examples below, E-XY stands for  $10^{-XY}$ . In the  
10 aberration diagram explained below, a solid line in the diagram  
illustrating spherical aberration expresses spherical aberration, and a  
broken line expresses sine condition, and a solid line in the diagram  
illustrating astigmatism expresses a sagittal image surface and a  
broken line expresses a meridional image surface. Further, in the  
15 respective aberration diagrams, d ray (587.56 nanometers) and g ray  
(435.83 nanometers) are illustrated.

Fig. 59 is a schematic diagram of an optical system of example  
4-1 of a zoom lens according to the present invention. The zoom lens  
includes a first lens E1, a second lens E2, a third lens E3, a fourth lens  
20 E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8,  
a ninth lens E9, a tenth lens E10, an eleventh lens E11, a twelfth lens  
E12, a diaphragm FA, an optical filter OF, and a cover glass CG. In  
this case, the first to the third lenses E1 to E3 constitute the first group  
optical system G1, the fourth to the seventh lenses E4 to E7 constitute

the second group optical system G2, the eighth lens E8 constitutes the third group optical system G3, the ninth to the eleventh lenses E9 to E11 constitute the fourth group optical system G4, and the twelfth lens E12 constitutes the fifth group optical system G5.

5           The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. In Fig. 59, parts of surface numbers that are assigned to each optical surface are shown for reference. The respective reference signs in Fig. 59 are  
10       used independently for each example, in order to avoid complexity due to an increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

          For example, the first lens E1, the second lens E2, the third lens  
15       E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the seventh lens E7, the diaphragm FA, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, the twelfth lens E12, an thirteenth E13, the optical filter OF, and the cover glass CG are arranged in order from the object side of a subject or the like to the  
20       image-surface side, and an image is formed at the back of the cover glass CG.

          The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3  
25       is a positive lens including a double-convex lens. The first lens E1 and

the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

5 The fourth lens E4 is a negative lens including a double-concave lens, the fifth lens E5 is a negative lens including a double-concave lens, the sixth lens E6 is a positive lens including a double-convex lens, and the seventh lens E7 is a negative lens including a double-concave lens. The second group optical system G2 formed of the fourth to the seventh lenses E4 to E7 exhibits a negative focal length as a whole.

10 The eighth lens E8 is a positive meniscus lens formed in a convex shape on the object side and only the eighth lens E8 forms the third group optical system G3 that exhibits a positive focal length. The ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a positive lens including a double-convex lens, and  
15 the eleventh lens E11 is a negative lens including a double-concave lens. The tenth to the eleventh lenses E10 to E11 form a densely cemented doublet, and the fourth group optical system G4 formed of the ninth to the eleventh lenses E9 to E11 exhibits a positive focal length as a whole. The twelfth lens E12 is a positive lens including a  
20 double-convex lens and only the twelfth lens E12 forms the fifth group optical system G5 that exhibits a positive focal length. The diaphragm FA arranged between the second group optical system G2 and the third group optical system G3 is integrally retained with the third group optical system G3 while keeping the distance from the third group  
25 optical system G3 constant.

On a side of the image surface of the twelfth lens E12 of the fifth group optical system G5, the optical filter OF that includes various optical filtering functions and the cover glass CG that protects an input surface of a solid image element are arranged in order toward the  
5 image-surface side and retained integrally with the solid image element.

The fourth surface, being a surface on the object side of the third lens E3 located closest to the image-surface side in the first group optical system G1, the sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second  
10 group optical system G2, the thirteenth surface, being a surface on the object side of the eighth lens E8 that forms the third group optical system G3, the fifteenth surface, being a surface on the object side of the ninth lens E9 located closest to the object side in the fourth group optical system G4, and the twentieth surface, being a surface on the  
15 object side of the twelfth lens E12 that forms the fifth group optical system G5 are respectively aspheric surfaces.

In example 4-1, the focal length  $f$  of the whole system, the F number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=7.404$  to  $71.820$ ,  $F=3.2$  to  $4.40$ , and  $\omega=33.497$  to  $3.705$ .  
20 The optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table.

**Table57** Optical characteristics

	R	D	N <sub>d</sub>	$\nu_d$	Note
1	39.503	1.200	1.84666	23.78	First lens
2	21.996	1.698	1.62041	60.34	Second lens
3	30.197	0.100			
4	17.527	3.047	1.72916	54.67	Third lens
5	200.671	d1			
6	155.019	0.800	1.83400	37.34	Fourth lens
7	6.861	2.456			
8	-16.851	0.800	1.48749	70.44	Fifth lens
9	9.243	2.000	1.80518	25.46	Sixth lens
10	83.105	d2			
11	Diaphragm	1.000			
12	11.210	1.377	1.48749	70.44	Seventh lens
13	37.911	d3			
14	9.969	2.748	1.48749	70.44	Eighth lens
15	-19.173	0.100			
16	13.122	0.809	1.84666	23.78	Ninth lens
17	8.048	1.989	1.51680	64.20	Tenth lens
18	17.504	1.001	1.80610	33.27	Eleventh lens
19	7.528	d4			
20	10.939	5.033	1.48749	70.44	Twelfth lens
21	59.964	d5			
22	Plane	0.927	1.54892	69.31	Filter
23	Plane	0.800			
24	Plane	0.500	1.50000	64.00	cover glass
25	Plane				

The respective optical surfaces on the fourth surface, the sixth surface, the thirteenth surface, the fifteenth surface, and the twentieth surface in Table 57 are respectively aspheric surfaces, and parameters relating to the expression (26) on each aspheric surface are as follows.

**Table58** Coefficient of aspheric surface

	K	$A_4$	$A_6$	$A_8$	$A_{10}$
4	-0.269	-3.464E-06	-2.330E-09	-1.572E-10	5.415E-13
6	342.566	6.456E-05	-6.388E-07	3.854E-09	-8.387E-11
12	-2.213	1.125E-04	-2.702E-06	1.473E-07	-5.625E-09
14	-1.535	-7.893E-05	7.904E-07	-5.165E-08	8.763E-10
20	-0.886	-1.084E-05	-2.426E-06	1.491E-07	-1.923E-09

The interval d1 between the first group optical system G1 and the second group optical system G2, the interval d2 between the second group optical system G2 and the diaphragm FA, the interval d3 between the third group optical system G3 and the fourth group optical system G4, the interval d4 between the fourth group optical system G4 and the fifth group optical system G5, and the interval d5 between the fifth group optical system G5 and the optical filter OF are variable, and these variable intervals d1, d2, d3, d4, and d5 are changed as shown in the following table, corresponding to the focal length f of the whole system, accompanying zooming.



**Table59** Variable intervals

	f	d 1	d 2	d 3	d 4	d 5
Wide	7.689	1.000	13.998	6.670	3.688	2.209
Mean	15.250	7.772	7.205	3.453	4.501	5.959
Tele	33.064	13.945	1.053	1.000	3.66859	9.20647

The parameter values according to the conditional expression (24) of the present invention in example 4-1 are as shown in the following table, and within the range of the conditional expression.

**Table60** Parameter values in the conditional expression

$R_{C2} / R_{C4}$	0.460
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The aberration diagrams at the wide-angle end (short focal end), the mean focal length, and the telephoto end (long focal end) according to example 4-1 are respectively illustrated in Fig. 63 to Fig. 65.

Fig. 60 is a schematic diagram of an optical system of example 4-2 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a twelfth lens E12, a diaphragm FA, an optical filter OF, and a cover glass CG. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the seventh lenses E4 to E7 constitute

the second group optical system G2, the eighth lens E8 constitutes the third group optical system G3, the ninth to the eleventh lenses E9 to E11 constitute the fourth group optical system G4, and the twelfth lens E12 constitutes the fifth group optical system G5.

5           The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. In Fig. 60, parts of surface numbers that are assigned to each optical surface are shown for reference. The respective reference signs in Fig. 60 are  
10       used independently for each example, in order to avoid complexity due to an increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

          For example, the first lens E1, the second lens E2, the third lens  
15       E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the seventh lens E7, the diaphragm FA, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, the twelfth lens E12, an thirteenth E13, the optical filter OF, and the cover glass CG are arranged in order from the object side of a subject or the like to the  
20       image-surface side, and an image is formed at the back of the cover glass CG.

          The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3  
25       is a positive lens including a double-convex lens. The first lens E1 and

the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

5 The fourth lens E4 is a negative lens including a double-concave lens, the fifth lens E5 is a negative lens including a double-concave lens, the sixth lens E6 is a positive lens including a double-convex lens, and the seventh lens E7 is a negative lens including a double-concave lens. The second group optical system G2 formed of the fourth to the seventh lenses E4 to E7 exhibits a negative focal length as a whole.

10 The eighth lens E8 is a positive meniscus lens formed in a convex shape on the object side and only the eighth lens E8 forms the third group optical system G3 that exhibits a positive focal length. The ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a positive lens including a double-convex lens, and  
15 the eleventh lens E11 is a negative lens including a double-concave lens. The tenth to the eleventh lenses E10 to E11 form a densely cemented doublet, and the fourth group optical system G4 formed of the ninth to the eleventh lenses E9 to E11 exhibits a positive focal length as a whole. The twelfth lens E12 is a positive lens including a  
20 double-convex lens and only the twelfth lens E12 forms the fifth group optical system G5 that exhibits a positive focal length. The diaphragm FA arranged between the second group optical system G2 and the third group optical system G3 is integrally retained with the third group optical system G3 while keeping the distance from the third group  
25 optical system G3 constant.

On a side of the image surface of the twelfth lens E12 of the fifth group optical system G5, the optical filter OF that includes various optical filtering functions and the cover glass CG that protects an input surface of a solid image element are arranged in order toward the  
5 image-surface side and retained integrally with the solid image element.

The fourth surface, being a surface on the object side of the third lens E3 located closest to the image-surface side in the first group optical system G1, the sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second  
10 group optical system G2, the thirteenth surface, being a surface on the object side of the eighth lens E8 that forms the third group optical system G3, the fifteenth surface, being a surface on the object side of the ninth lens E9 located closest to the object side in the fourth group optical system G4, and the twentieth surface, being a surface on the  
15 object side of the twelfth lens E12 that forms the fifth group optical system G5 are respectively aspheric surfaces.

In example 4-2, the focal length  $f$  of the whole system, the F number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=7.400$  to  $71.776$ ,  $F=3.200$  to  $4.400$ , and  $\omega=33.512$  to  $3.707$ .  
20 The optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table.

**Table61** Optical characteristics

	R	D	N <sub>d</sub>	$\nu_d$	Note
1	47.161	1.200	1.84666	23.78	First lens
2	23.691	1.839	1.62041	60.34	Second lens
3	38.330	0.100			
4	18.603	2.988	1.72916	54.67	Third lens
5	524.119	d1			
6	184.692	0.800	1.834	37.34	Fourth lens
7	6.747	2.418			
8	-14.187	0.804	1.48749	70.44	Fifth lens
9	9.514	2.187	1.80518	25.46	Sixth lens
10	216.270	13.637	d2		
11	Diaphragm	1.033			
12	11.374	1.293	1.48749	70.44	Seventh lens
13	27.483	d3			
14	10.783	2.744	1.48749	70.44	Eighth lens
15	-17.861	0.108			
16	16.243	1.095	1.92300	20.90	Ninth lens
17	13.963	1.483	1.48700	70.40	Tenth lens
18	20.000	1.318	1.92300	20.90	Eleventh lens
19	8.652	d4			
20	12.261	5.116	1.48749	70.44	Twelfth lens
21	442.676	d5			
22	Plane	0.927	1.54892	69.31	Filter
23	Plane	0.800			
24	Plane	0.500	1.50000	64.00	cover glass
25	Plane				

The respective optical surfaces on the fourth surface, the sixth surface, the thirteenth surface, the fifteenth surface, and the twentieth surface in Table 61 are respectively aspheric surfaces, and parameters relating to the expression (26) on each aspheric surface are as follows.

**Table62** Coefficient of aspheric surface

	K	$A_4$	$A_6$	$A_8$	$A_{10}$
4	-0.282	-3.799E-06	-2.563E-09	-1.714E-10	7.389E-13
6	541.182	6.866E-05	-7.206E-07	2.180E-10	-2.017E-11
12	-2.300	1.074E-04	-2.446E-06	1.228E-07	-4.807E-09
14	-1.588	-8.454E-05	8.975E-07	-4.394E-08	6.855E-10
20	-1.184	-3.805E-05	-2.098E-06	8.476E-08	-1.030E-09

The interval d1 between the first group optical system G1 and the second group optical system G2, the interval d2 between the second group optical system G2 and the diaphragm FA, the interval d3 between the third group optical system G3 and the fourth group optical system G4, the interval d4 between the fourth group optical system G4 and the fifth group optical system G5, and the interval d5 between the fifth group optical system G5 and the optical filter OF are variable, and these variable intervals d1, d2, d3, d4, and d5 are changed as shown in the following table, corresponding to the focal length f of the whole system, accompanying zooming.

**Table63** Variable intervals

	f	d 1	d 2	d 3	d 4	d 5
Wide	7.697	1.000	13.637	6.606	4.661	2.208
Mean	15.250	7.575	7.067	3.358	5.325	5.862
Tele	33.102	13.616	1.020	1.000	4.438	9.135

The parameter values according to the conditional expression (24) of the present invention in example 4-2 are as shown in the following table, and within the range of the conditional expression.

**Table64** Parameter values in the conditional expression

$R_{C2} / R_{C4}$	0.698
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The aberration diagrams at the wide-angle end (short focal end), the mean focal length, and the telephoto end (long focal end) according to example 4-2 are respectively illustrated in Fig. 66 to Fig. 68.

Fig. 61 is a schematic diagram of an optical system of example 4-3 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a twelfth lens E12, a diaphragm FA, an optical filter OF, and a cover glass CG. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the seventh lenses E4 to E7 constitute

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the second group optical system G2, the eighth lens E8 constitutes the third group optical system G3, the ninth to the eleventh lenses E9 to E11 constitute the fourth group optical system G4, and the twelfth lens E12 constitutes the fifth group optical system G5.

5           The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of zooming, each group optical system integrally operates. In Fig. 61, parts of surface numbers that are assigned to each optical surface are shown for reference. The respective reference signs in Fig. 61 are  
10       used independently for each example, in order to avoid complexity due to an increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

          For example, the first lens E1, the second lens E2, the third lens  
15       E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the seventh lens E7, the diaphragm FA, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, the twelfth lens E12, an thirteenth E13, the optical filter OF, and the cover glass CG are arranged in order from the object side of a subject or the like to the  
20       image-surface side, and an image is formed at the back of the cover glass CG.

          The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3  
25       is a positive meniscus lens formed in a convex shape on the object side.



The first lens E1 and the second lens E2 form a densely cemented doublet, and the first group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

5 The fourth lens E4 is a negative lens including a double-concave lens, the fifth lens E5 is a negative lens including a double-concave lens, the sixth lens E6 is a positive lens including a double-convex lens, and the seventh lens E7 is a negative lens including a double-concave lens. The second group optical system G2 formed of the fourth to the seventh lenses E4 to E7 exhibits a negative focal length as a whole.

10 The eighth lens E8 is a positive meniscus lens formed in a convex shape on the object side and only the eighth lens E8 forms the third group optical system G3 that exhibits a positive focal length. The ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a positive lens including a double-convex lens, and  
15 the eleventh lens E11 is a negative lens including a double-concave lens. The tenth to the eleventh lenses E10 to E11 form a densely cemented doublet, and the fourth group optical system G4 formed of the ninth to the eleventh lenses E9 to E11 exhibits a positive focal length as a whole. The twelfth lens E12 is a positive meniscus lens formed in a  
20 convex shape on the object side and only the twelfth lens E12 forms the fifth group optical system G5 that exhibits a positive focal length. The diaphragm FA arranged between the second group optical system G2 and the third group optical system G3 is integrally retained with the third group optical system G3 while keeping the distance from the third  
25 group optical system G3 constant.

On a side of the image surface of the twelfth lens E12 of the fifth group optical system G5, the optical filter OF that includes various optical filtering functions and the cover glass CG that protects an input surface of a solid image element are arranged in order toward the  
5 image-surface side and retained integrally with the solid image element.

The fourth surface, being a surface on the object side of the third lens E3 located closest to the image-surface side in the first group optical system G1, the sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second  
10 group optical system G2, the thirteenth surface, being a surface on the object side of the eighth lens E8 that forms the third group optical system G3, the fifteenth surface, being a surface on the object side of the ninth lens E9 located closest to the object side in the fourth group optical system G4, and the twentieth surface, being a surface on the  
15 object side of the twelfth lens E12 that forms the fifth group optical system G5 are respectively aspheric surfaces.

In example 4-3, the focal length  $f$  of the whole system, the F number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=7.4$  to  $71.78$ ,  $F=3.1$  to  $4.3$ , and  $\omega=33.511$  to  $3.707$ . The  
20 optical characteristics relating to the respective optical surfaces and the optical elements are as shown in the following table.

**Table65** Optical characteristics

	R	D	N <sub>d</sub>	$\nu_d$	Note
1	43.559	1.200	1.84666	23.78	First lens
2	23.072	1.758	1.62041	60.34	Second lens
3	34.177	0.100			
4	17.934	2.983	1.72916	54.67	Third lens
5	197.504	d1			
6	144.256	0.800	1.834	37.34	Fourth lens
7	6.811	2.436			
8	-16.739	0.800	1.48749	70.44	Fifth lens
9	9.138	2.027	1.80518	25.46	Sixth lens
10	89.180	d2			
11	Diaphragm	1.223			
12	11.254	1.368	1.48749	70.44	Seventh lens
13	32.211	d3			
14	10.567	2.831	1.48749	70.44	Eighth lens
15	-17.288	0.100			
16	21.737	0.800	1.60300	38.00	Ninth lens
17	11.694	1.652	1.48700	70.40	Tenth lens
18	20.000	0.978	1.92300	20.90	Eleventh lens
19	9.504	d4			
20	11.960	7.034	1.48749	70.44	Twelfth lens
21	72.212	d5			
22	Plane	0.927	1.54892	69.31	Filter
23	Plane	0.800			
24	Plane	0.500	1.50000	64.00	cover glass
25	Plane				

The respective optical surfaces on the fourth surface, the sixth surface, the thirteenth surface, the fifteenth surface, and the twentieth surface in Table 65 are respectively aspheric surfaces, and parameters relating to the expression (26) on each aspheric surface are as follows.

**Table66** Coefficient of aspheric surface

	K	$A_4$	$A_6$	$A_8$	$A_{10}$
4	-0.273	-3.577E-06	1.296E-09	-2.017E-10	8.571E-13
6	378.650	6.767E-05	-9.957E-07	1.095E-08	-2.145E-10
12	-2.230	1.111E-04	-3.230E-06	1.823E-07	-6.120E-09
14	-1.590	-8.528E-05	6.634E-07	-4.513E-08	7.328E-10
20	-1.305	-4.698E-05	-2.384E-06	9.838E-08	-1.359E-09

5 The interval d1 between the first group optical system G1 and the second group optical system G2, the interval d2 between the second group optical system G2 and the diaphragm FA, the interval d3 between the third group optical system G3 and the fourth group optical system G4, the interval d4 between the fourth group optical system G4 and the fifth group optical system G5, and the interval d5 between the fifth group optical system G5 and the optical filter OF are variable, and these variable intervals d1, d2, d3, d4, and d5 are changed as shown in the following table, corresponding to the focal length f of the whole system, accompanying zooming.

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**Table67** Variable intervals

	f	d 1	d 2	d 3	d 4	d 5
Wide	7.699	1.000	14.123	6.740	3.783	2.220
Mean	15.247	7.828	7.295	3.383	4.658	5.874
Tele	33.105	14.072	1.050	1.000	3.582	9.089

The parameter values according to the conditional expression (24) of the present invention in example 4-3 are as shown in the following table, and within the range of the conditional expression.

**Table68** Parameter values in the conditional expression

$R_{C2}/R_{C4}$	0.598
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The aberration diagrams at the wide-angle end (short focal end), the mean focal length, and the telephoto end (long focal end) according to example 4-3 are respectively illustrated in Fig. 69 to Fig. 71.

Fig. 62 is a schematic diagram of an optical system of example 4-4 of a zoom lens according to the present invention. The zoom lens includes a first lens E1, a second lens E2, a third lens E3, a fourth lens E4, a fifth lens E5, a sixth lens E6, a seventh lens E7, an eighth lens E8, a ninth lens E9, a tenth lens E10, an eleventh lens E11, a twelfth lens E12, a diaphragm FA, an optical filter OF, and a cover glass CG. In this case, the first to the third lenses E1 to E3 constitute the first group optical system G1, the fourth to the seventh lenses E4 to E7 constitute the second group optical system G2, the eighth lens E8 constitutes the

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third group optical system G3, the ninth to the eleventh lenses E9 to E11 constitute the fourth group optical system G4, and the twelfth lens E12 constitutes the fifth group optical system G5.

The respective lenses are supported by an appropriate common support frame or the like for each lens group, and at the time of  
5 zooming, each group optical system integrally operates. In Fig. 62, parts of surface numbers that are assigned to each optical surface are shown for reference. The respective reference signs in Fig. 62 are used independently for each example, in order to avoid complexity due  
10 to an increase in number of digits of the reference signs. Therefore, even when a common reference sign is given, it is not always a common configuration to other examples.

For example, the first lens E1, the second lens E2, the third lens E3, the fourth lens E4, the fifth lens E5, the sixth lens E6, the seventh  
15 lens E7, the diaphragm FA, the eighth lens E8, the ninth lens E9, the tenth lens E10, the eleventh lens E11, the twelfth lens E12, an thirteenth E13, the optical filter OF, and the cover glass CG are arranged in order from the object side of a subject or the like to the image-surface side, and an image is formed at the back of the cover  
20 glass CG.

The first lens E1 is a negative meniscus lens formed in a convex shape on the object side, the second lens E2 is a positive meniscus lens formed in a convex shape on the object side, and the third lens E3 is a positive lens including a double-convex lens. The first lens E1 and  
25 the second lens E2 form a densely cemented doublet, and the first

group optical system G1 formed of the first to the third lenses E1 to E3 exhibits a positive focal length as a whole.

The fourth lens E4 is a negative lens including a double-concave lens, the fifth lens E5 is a negative lens including a double-concave lens, the sixth lens E6 is a positive lens including a double-convex lens, and the seventh lens E7 is a negative lens including a double-concave lens. The second group optical system G2 formed of the fourth to the seventh lenses E4 to E7 exhibits a negative focal length as a whole.

The eighth lens E8 is a positive meniscus lens formed in a convex shape on the object side and only the eighth lens E8 forms the third group optical system G3 that exhibits a positive focal length. The ninth lens E9 is a positive lens including a double-convex lens, the tenth lens E10 is a positive lens including a double-convex lens, and the eleventh lens E11 is a negative lens including a double-concave lens. The tenth to the eleventh lenses E10 to E11 form a densely cemented doublet, and the fourth group optical system G4 formed of the ninth to the eleventh lenses E9 to E11 exhibits a positive focal length as a whole. The twelfth lens E12 is a positive meniscus lens formed in a convex shape on the object side and only the twelfth lens E12 forms the fifth group optical system G5 that exhibits a positive focal length. The diaphragm FA arranged between the second group optical system G2 and the third group optical system G3 is integrally retained with the third group optical system G3 while keeping the distance from the third group optical system G3 constant.

On a side of the image surface of the twelfth lens E12 of the fifth

group optical system G5, the optical filter OF that includes various optical filtering functions and the cover glass CG that protects an input surface of a solid image element are arranged in order toward the image-surface side and retained integrally with the solid image element.

5           The fourth surface, being a surface on the object side of the third lens E3 located closest to the image-surface side in the first group optical system G1, the sixth surface, being a surface on the object side of the fourth lens E4 located closest to the object side in the second group optical system G2, the thirteenth surface, being a surface on the  
10 object side of the eighth lens E8 that forms the third group optical system G3, the fifteenth surface, being a surface on the object side of the ninth lens E9 located closest to the object side in the fourth group optical system G4, and the twentieth surface, being a surface on the object side of the twelfth lens E12 that forms the fifth group optical  
15 system G5 are respectively aspheric surfaces.

          In example 4-4, the focal length  $f$  of the whole system, the F number  $F$ , and the half angle of view,  $\omega$ , respectively change in the range of  $f=7.4$  to  $71.774$ ,  $F=3.2$  to  $4.4$ , and  $\omega=33.511$  to  $3.707$ . The optical characteristics relating to the respective optical surfaces and the  
20 optical elements are as shown in the following table.



**Table69** Optical characteristics

	R	D	N <sub>d</sub>	$\nu_d$	Note
1	34.036	1.200	1.84666	23.78	First lens
2	19.769	1.966	1.62041	60.34	Second lens
3	30.362	0.100			
4	17.339	3.019	1.72916	54.67	Third lens
5	195.185	d1			
6	230.407	0.800	1.83400	37.34	Fourth lens
7	6.777	2.937			
8	-19.058	0.800	1.48749	70.44	Fifth lens
9	8.914	1.920	1.80518	25.46	Sixth lens
10	54.357	d2			
11	Diaphragm	1.000			
12	12.162	1.361	1.48749	70.44	Seventh lens
13	58.506	d3			
14	11.347	2.840	1.48749	70.44	Eighth lens
15	-16.632	0.798			
16	14.766	0.800	1.92300	20.90	Ninth lens
17	8.792	2.289	1.48700	70.40	Tenth lens
18	20.000	1.239	1.60300	38.00	Eleventh lens
19	7.317	d4			
20	9.728	3.929	1.48749	70.44	Twelfth lens
21	36.166	d5			
22	Plane	0.927	1.54892	69.31	Filter
23	Plane	0.800			
24	Plane	0.500	1.50000	64.00	cover glass
25	Plane				

The respective optical surfaces on the fourth surface, the sixth surface, the thirteenth surface, the fifteenth surface, and the twentieth surface in Table 13 are respectively aspheric surfaces, and parameters relating to the expression (26) on each aspheric surface are as follows.

**Table70** Coefficient of aspheric surface

	K	$A_4$	$A_6$	$A_8$	$A_{10}$
4	-0.251	-2.763E-06	-6.163E-09	-1.076E-10	3.020E-13
6	969.687	5.595E-05	-3.115E-07	-4.985E-09	1.574E-12
12	-2.608	8.857E-05	-2.893E-06	1.041E-07	-2.967E-09
14	-1.710	-9.767E-05	8.163E-07	-4.625E-08	7.683E-10
20	-0.634	1.945E-05	-1.746E-06	1.143E-07	-9.014E-10

5 The interval d1 between the first group optical system G1 and the second group optical system G2, the interval d2 between the second group optical system G2 and the diaphragm FA, the interval d3 between the third group optical system G3 and the fourth group optical system G4, the interval d4 between the fourth group optical system G4 and the fifth group optical system G5, and the interval d5 between the fifth group optical system G5 and the optical filter OF are variable, and these variable intervals d1, d2, d3, d4, and d5 are changed as shown in the following table, corresponding to the focal length f of the whole system, accompanying zooming.

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**Table71** Variable intervals

	f	d 1	d 2	d 3	d 4	d 5
Wide	7.700	1.000	12.913	7.359	1.656	2.268
Mean	15.251	6.989	6.905	3.623	3.915	3.363
Tele	33.113	12.816	1.077	1.000	4.680	4.721

The parameter values according to the conditional expression (24) of the present invention in example 4-4 are as shown in the following table, and within the range of the conditional expression.

**Table72** Parameter values in the conditional expression

$R_{C2}/R_{C4}$	0.44
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The aberration diagrams at the wide-angle end (short focal end), the mean focal length, and the telephoto end (long focal end) according to example 4-4 are respectively illustrated in Fig. 72 to Fig. 74. In example 1 to example 4-4, as the lens material for all lenses, an optical glass that is chemically stable and does not contain any toxic substance such as lead or arsenic can be used, the materials can be recycled, without having water pollution due to waste fluid at the time of machining.

According to the sixth embodiment, a zoom lens, which is sufficiently small, can achieve a high magnification, and can obtain a high resolving power corresponding to the image capturing device with 3,000,000 to 5,000,000 pixels, a camera using the zoom lens as the

shooting optical system, and a mobile information terminal using the zoom lens as the shooting optical system in the camera unit can be provided.

Although the invention has been described with respect to a  
5 specific embodiment for a complete and clear disclosure, the appended claims are not to be thus limited but are to be construed as embodying all modifications and alternative constructions that may occur to one skilled in the art which fairly fall within the basic teaching herein set forth.

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